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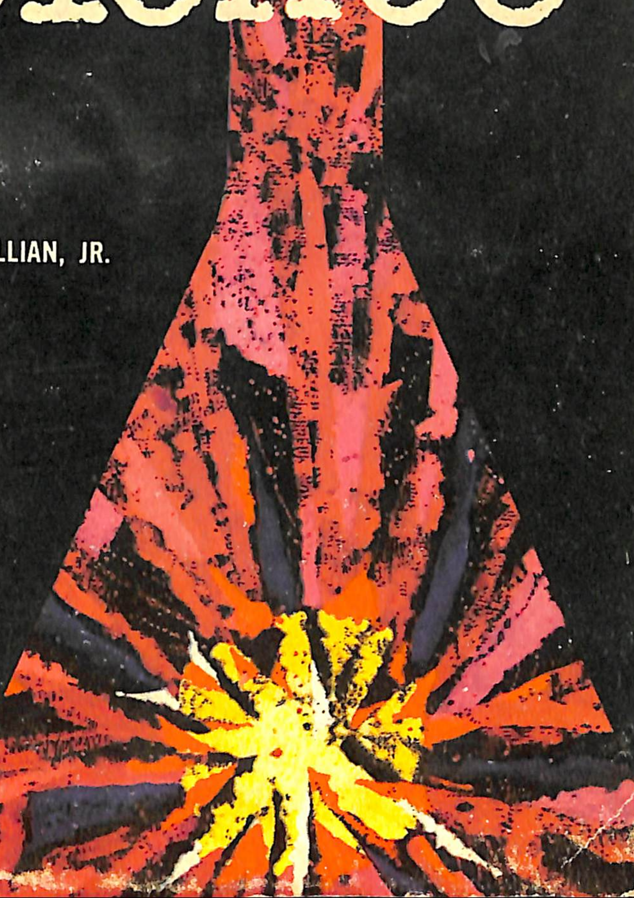
NEW WORLDS OF modern science

A TREASURY

Edited by
LEONARD ENGEL

Introduction by
DR. JAMES R. KILLIAN, JR.
President, M.I.T.

EVOLUTION
RELATIVITY
ATOMIC ENERGY
ELECTRONICS
SYNTHETICS
ANTHROPOLOGY
PSYCHIATRY
MEDICINE
RADIO-ASTRONOMY



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from the Foreword by Leonard Engel

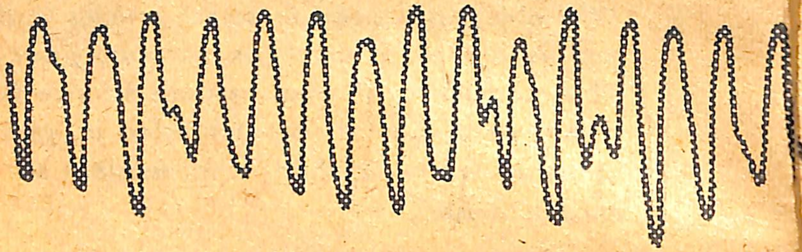
"My object has been to select articles and papers that tell, as simply as reasonably possible, something of what modern science is doing, what scientists are interested in, and how they work—in short, what modern science is about."

about the Editor

One of America's most experienced writers on science, Leonard Engel has pioneered in the field of popularization for the layman for the last twenty years. He is probably the most outstanding popular writer in the field today.

Mr. Engel is a regular contributor of scientific articles to *The New York Times* and *Harper's Bazaar*, and frequently publishes articles in other top American and international journals. He was awarded the George Pope Memorial Award in 1953, for distinguished journalism in science and medicine.

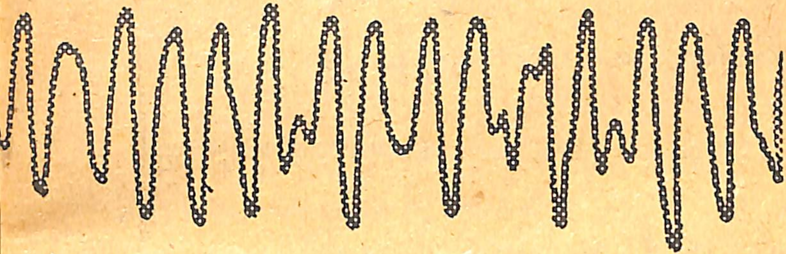
New Worlds of



A TREASURY

EDITED BY LEONARD ENGEL

Modern Science



INTRODUCTION BY JAMES R. KILLIAN, JR.

President of the Massachusetts Institute of Technology

A Dell First Edition

Published by
DELL PUBLISHING COMPANY, INC.
261 Fifth Avenue
New York 16, N. Y.

Library of Congress Catalog Card 56-5402

Designed and produced by
Western Printing and Lithographing Company

Cover design by Seymour Chwast

Printed in U. S. A.

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Editor's Preface

Anthologies are often billed as offering the reader the "best" writings of their kind to be had, whatever that kind may be. Aside from the fact that such claims are too presumptuous for my taste, a description of this anthology as a collection of "best" writings on science would miss the mark. I haven't tried to pick the "best" writings on science. My object has been to select, instead, articles and papers that tell, as simply as reasonably possible, something of what modern science is doing, and what scientists are interested in and how they work—in short, something of what modern science is about.

Most of the selections are from the writing of professional scientists. The reason for this is simple. Scientists are not often able to write understandably about science. But when they can, they are apt to be much better at it than professional writers. They know their subjects better. They are not gushingly naïve about science (though they may be as naïve about other matters as the rest of us).

Of course, scientists have not written good popular articles about every interesting aspect of modern science. So I have not hesitated to use the work of journalists when that seemed best.

A casual glance through the table of contents will disclose the omission of many interesting fields of scientific work. This is due mainly to the impossibility of compressing so vast an enterprise as modern science into a single book. It is also due, however, to the circumstance that there are important scientific activities of which no one—whether scientist or journalist—has yet given an adequate account that anyone but a specialist could understand. An example is research on photosynthesis, the remarkable process by which green plants convert the energy of sunlight into food. Since World War II, a good deal has been

learned about photosynthesis. Up to the time this book went to press, though, no article or recent work on photosynthesis suitable for the general reader had been published anywhere that I know of. I hope it will be possible to remedy omissions like this in a future edition of this anthology.

I owe thanks for suggestions and advice on this anthology to friends in the scientific and writing communities too numerous to identify. I owe also particular thanks to Mildred Kapilow, who did a most efficient job of arranging permissions; and to Evelyn M. Jensen and Mrs. Paul B. Hoeber, who had the laborious jobs of typing the manuscript and checking copy.

Leonard Engel

JAMES R. KILLIAN, JR.

Introduction

Dr. Killian is President of the Massachusetts Institute of Technology.

Science and its applications are serving our national security and furthering peace in two special ways at this juncture of world affairs. By steadily increasing the power of weapons, it is deterring war; hopefully it may be helping, through the awful power of these weapons, to convince the nations of the world that total war is no longer possible as an instrument of national policy. Today a major thermo-nuclear war would be a war of nearly total destruction for all participants.

The second way in which science is reducing the will for war, and thus helping to increase world security, is by producing at an accelerating rate new means of improving man's lot—his health, his standard of living, his standard of understanding, and his opportunities for spirtual growth. May not the breathtaking possibilities in the peaceful use of the atom so command the energies and imagination of man that he will conclude he can gain more from nature than from fighting? Within the United States this concept has powerfully influenced our national career. As Professor F. S. C. Northrup and others have pointed out, one of the indigenous and controlling concepts of American society is the conviction that we can put nature to work for beneficent social purposes; we can augment our strength by technology rather than by conquest, by isms, or by social panaceas.

Through the conquests of science, not only in such fields as atomic energy but also in all the many burgeoning branches of science, we can multiply man's energy and understanding and

thus his wealth and well-being. If we can do this, may we not also achieve a world revolution that will reduce the ranks of the have-nots and thereby release the tensions that arise from want and despair? May we not really show that Toynbee was right when he predicted that this century could be the "first age since the dawn of civilization . . . in which people dared to think it practical to make the benefits of civilization available to the whole human race?"

In suggesting these possible benign effects of the current outpouring of scientific discoveries and technology, I do not wish to be blind to the duality of this power. It can be used for evil and destruction, as well as for growth and for the benefit of the "whole human race." This is true of all forms of knowledge and power, of which science is only one. The solution is not to prevent the tide of knowledge from rolling on. Hope lies in all the array of means—political, philosophical, moral, spiritual—whereby man seeks to control himself.

Today our great problem and opportunity is to let science be itself and thus realize its full potential for good. The beneficent applications of science should be given a clear field to reduce the forces tending toward war. The hazard we face is that science will be so identified with destruction, and so hemmed in by security considerations, that its real significance will be lost, its ranks weakened, and its creativity diminished. If American science is to continue to prosper, if it is to continue to attract its proper complement of creative and gifted minds, scientists must combat the notions that science and engineering are incompatible with the disciplines of the great humanities, that they are narrowly materialistic and destructive of human values.

We live in a period marked by both subtle and gross assaults on intellectual life. The whole domain of science has been represented as endangering man's nobler aims and ends. In the face of the practical responsibilities which rest in science for our security and our material welfare, it is all too easy for people to become bemused by the sophistry that science is inimical to the spiritual ends of life. They fail to understand that, instead, it is one of man's most powerful and noble means for searching out truth and for augmenting man's dignity by augmenting his understanding. Scientists have an obligation to

make this true character of science better understood, but not by the arrogant advocacy of science and technology as the only means of increasing our understanding and well-being. They must, instead, advocate the balanced and tolerant presentation of the scientific spirit as one of the great, powerful methods by which man can increase his knowledge and understanding, yet still stand humble and ennobled before the wonder and the majesty of what he does not understand. When thus perceived and carried forward, and when not misused for ignoble ends, science is a major means for "making gentle the life of mankind."

II

The misapprehensions about the nature and purposes of science which have been discussed above may be one of the factors underlying the current shortage of scientists. Every reader of this book must be aware that today the need for scientists and engineers is far greater than the number who are ready to assume these responsibilities. While the United States has experienced shortages of professional talent in the past (notably of physicians), we have not in many years experienced so great or persistent an imbalance between supply and demand as is currently present in science and engineering. The sustained scarcity of professional manpower in these fields, having been widely proclaimed, is now generally recognized, and its handicap to the nation is becoming understood.

Not so well recognized or understood is the qualitative nature of the shortage. We have a shortage of young engineers who are competent to handle new, advanced technologies. We have a shortage of research scientists and engineers, the demand for whom has been doubling every decade. We have an acute shortage of scientists whose creative and conceptualizing powers are exceptional. In summary, our shortage is of basically educated, versatile young talent, rather than of mere numbers.

There is, indeed, a shortage of numbers in many, but not all, fields of science and engineering. We could better cope with such a shortage if we did not also have a severe shortage of quality, depth, adaptability, and up-to-dateness.

The quality of American science and engineering depends upon many factors. It depends upon those attitudes in our society which tend to place a high value on accomplishment in these fields, and which affect the motivations and the recognition so vital to achievement in any field. It depends upon whether our society values and rewards creative intelligence. Above all, it depends upon the success of our society in identifying, encouraging, and providing special educational opportunity for its exceptionally talented young people.

In recent years the United States has rounded out a public system of mass education which is magnificent in its accomplishment. We must maintain this system in a state of vigor; we must make sure that we provide the means for it to meet the swelling numbers that result from our rapid growth in population. But we must do more. We must make sure that our public school system maintains the methods, the ideals, and the people who will spot able youngsters and give them special opportunities so that they may make a maximum contribution to our society. All too frequently the youngster of exceptional intellectual ability is the underprivileged youngster in our schools.

One-third of the top two per cent of the graduates of our high schools are not going to college. Some are not motivated; some do not have the means. To augment the quality of our science and other professional work, we must provide the motivation and the means for more of this missing third to get a college education.

The quality of American science and engineering depends also upon strengthening science teaching in the secondary schools. In June, 1955, teachers' colleges and other institutions graduated less than 250 teachers of physics for our secondary schools. Half of these were attracted away from teaching by industry and government. At present rates of education, we will train only half the number of science teachers we will need to maintain present standards during the next five years. We have, therefore, a shortage of science teachers, due first to their attraction into more remunerative fields—mainly industry—and secondly to the inadequate status and emphasis given science in secondary schools. In remarking this, I hasten to make clear that I do not feel that the teaching of science should

be given such overriding attention and privilege in our public schools that other fields are weakened, and the curriculum distorted, as a result. This is not the way to solve the problem. I do think the evidence is clear that in the secondary schools science teaching has suffered more than teaching in any other field.

While the quantity and quality of scientific manpower are affected by many factors, I feel sure that one of the most important ways to insure a steady flow of first-rate young minds into the scientific field is to widen the public understanding of science.

III

Another condition which calls for better public understanding of science is the impact of science on public policy and the impact of public policy on science. The Federal government now spends over two billion dollars a year on research. As the principal source of all research funds, the government profoundly influences our entire national research effort. The ways whereby the government reaches decisions on how to spend its research funds, and the wisdom it uses in reaching these decisions, have a new order of importance in our national life, and the citizen has a stake in research hardly dreamed of even a quarter century ago.

Clearly, the makers of public policy and the citizens they represent need as never before to increase their understanding of science. If we are to maintain a favorable environment for scientific advancement, and if the nation is to deal wisely with the great technological forces of our time, it is vital that the scientist speak out of his specialized knowledge on the meaning of science to our society.

We have urgent need of more scientists and engineers who can build bridges of understanding between the domain of science and the domain of non-science. We need a growing body of exposition to make science and scientific activity understandable to laymen. Therein lies the importance of books such as this one.

1. The World of Science

LEONARD ENGEL

The World That Science Deals With

The following article was written especially for this book.

Throughout much of western history, philosophers have been concerned with the nature of knowledge and the relation between what we know and the world outside. The question was, is the world real, and thought essentially a reflection of the world within the mind? Or is thought the ultimate reality? Putting it another way, does the world exist apart from what we perceive and therefore know of it, or is what we perceive the end of things? Would the sea be blue in the absence of anyone to see or know blueness?

An answer may be inferred. Thus, I am sure the sea would still be blue if man ceased to exist (and perhaps even a little bluer, owing to the diminution of pollution). But neither this nor the contrary view can be proved by strictly logical means —which may be one reason why the question was debated so long and with so much heat.

This kind of question is seldom asked nowadays. It isn't that man is less curious or less profound than he used to be. The question is no longer asked because science has, in a way, settled it.

Science and scientists act as though the world were real and had an existence quite apart from and beyond what we know and perceive. Scientists are forever sharpening their perceptions

and pushing into the unknown, and finding something there to be perceived. Scientists also take great pains to exclude opinion and their own errors as observers from experimental results; this implies a belief in an "objective" world. So does the important scientific activity of generalizing from observation and formulating natural "laws."

At root, however, the belief in an "objective" world is an unprovable assumption. For scientists are no more able than philosophers to prove that which is not known, and they cannot *know* any better than philosophers what lies beyond that which has already been perceived. But science has been so successful that it rarely occurs to anyone to challenge the assumption the world is real. Through science, people are so busy doing things that they attach little importance to the question of whether objective reality really exists.

The world that science deals with is usually divided into three areas: the area of the natural or physical sciences, the biological sciences, and the social sciences respectively. The physical sciences take in phenomena like heat, light, and gravitation, the laws of mechanics, the basic principles of chemical combination, and (more recently) the structure of the atom. The biological sciences deal with the world of living creatures, from smallest to largest. The social sciences deal primarily with man as a social animal. (For a more detailed classification of the sciences, see the diagram "The Family Tree of Science" and accompanying text on pages 21 to 25.)

Of course, man has been interested in all aspects of the world around him since early times; even the ancients wrote extensively, if not always with the same approach as we, in all three areas of science. But the physical sciences were the first to develop into modern form. The process began in Europe in the thirteenth to fifteenth centuries. Physics emerged into what a modern physicist would readily recognize as physics with Galileo in the seventeenth.

Physics came first partly because of the close relationship between physical science, on the one hand, and mechanics and branches of military science like ballistics, on the other. It was first also because some of the phenomena it deals with (such as the laws of falling bodies and of gas pressure) are compara-

tively easy to observe. Animals and plants are more variable and harder to make observations on. So it was not until the eighteenth century that systematic methods of classifying plants and animals were worked out, and biology's first great general law—Charles Darwin's law of organic evolution—was published only in 1859. Physiology, the branch of biology that studies how plants and animals work, is a product mainly of the twentieth century.

The social sciences have the most complex subject matter of the three areas of science, and the most recent origin. In fact, they have hardly entered the first stage in the development of any science—the description of phenomena. In most of the social sciences, the formulation of enduring, useful general laws seems still to be some distance off.

In the course of the past half century particularly, scientific work and scientific workers have both multiplied enormously. The result has been the rapid growth of specialization. Scientific investigators have, too often, been reduced to a species of mole, digging away each in his own tunnel, completely unaware of what is going on in the next tunnel, indeed, hardly aware that there is a next tunnel.

The mushroom growth of specialization has probably been unavoidable. Even in small sectors of science, research workers have accumulated unmanageable bodies of information and special techniques it may take a lifetime to learn. The swift spread of specialization has nevertheless been doubly unfortunate. By raising barriers between related fields, it has cost the world many useful discoveries and greatly delayed others (like the anti-tubercular compound isoniazid, which was prepared by chemists in 1912, but not found effective in tuberculosis until thirty-nine years later). More serious, specialization fragments nature, giving to each scientific specialist and to all together a distorted view of what they study.

For the world that science deals with is a single world, however diverse its different faces appear. There is an intimate connection among the sub-worlds covered by the natural, the biological, and the social sciences. Each has its own laws; but living organisms also obey the laws of chemistry and physics; and man is at once a social phenomenon, a biological organism,

and an exceedingly intricate bundle of physical and chemical events.

If this were not so, modern medicine would have few of the wonder drugs that have revolutionized medical care, for most of these drugs are products of the chemical laboratory; and science generally would be without the wealth of instruments with which observations are made and facts ascertained, for these instruments are mainly the product of physics and utilize physical principles to make their observations, in whatever field these instruments may be used. For example, antibiotics would not be found in the drugstore had chemists not discovered practical means for producing and purifying them; and astrophysics and chemistry alike would be without that superb tool of analysis, the spectroscope, a product of the physicist's study of light.

During the eighteenth century, a school of French savants, the Physiocrats, attempted to apply to the analysis of society the procedures and laws of the physical sciences, especially Newtonian physics. The attempt was naïve and foredoomed to end merely as a curious footnote in man's intellectual history, for society is more complex than classical physics. But the Physiocrats were nearer right than some of their critics, for they at least recognized the existence of a real link between man and nature and they had the useful idea of bringing the insights of one field of science to bear in another.

The connection among the three areas of science is something like the relation between single- and multicelled living organisms. As we go up through the evolutionary scale, we find life more varied but also more complex. Each form of life has properties and capabilities peculiar to itself. But each is also made up of individual cells that "work" in much the same way as the single cells from which life originally came. Multicelled organisms integrate individual cells into a whole that functions at once in its own way and in accordance with the properties of its individual cellular constituents.

It is a truism that living organisms cannot be understood without taking the cell into account. It is no less true that society cannot be studied without reference to biology, or biology without reference to physics and chemistry. The most rapid progress in science is coming, and will continue to come, from

the "new" sciences like biochemistry and biophysics, which apply the skills and knowledge of several fields of science to common problems and give practical recognition to the fact that the world that science deals with is one.

Notes on diagram "THE FAMILY TREE OF SCIENCE" (see next two pages)

The diagram on the next two pages lists a number of the main branches of science and illustrates the relationships among them. Applied sciences, as distinguished from "pure" sciences, appear in italics. The lines connect closely allied sciences; thus, as the diagram shows, medicine draws not only on the various branches of zoölogy, but on biochemistry, biophysics and microbiology, and medicine both contributes to and draws on psychiatry.

Three features of the diagram require comment. First, mathematics is listed separately and not with other sciences. This is no accident. Although mathematicians like to think of it as "queen of the sciences," mathematics is not a science, but a tool of science. Of course, mathematics has a life of its own; mathematicians study mathematical propositions without reference to their possible usefulness in science or anything else. But the laws of mathematics are laws of thought and not of the world which, in its many aspects, is what science is concerned with. Laws of nature deduced with the aid of mathematics become laws of nature only when confirmed by observation. Mathematics is a useful tool in nearly all branches of science, though it has been most useful to date in the physical sciences.

The second necessary comment is on the small number of entries in the right-hand column, under social sciences. This reflects the fact that the subject matter of the social sciences—man in society—is peculiarly difficult, and has hardly begun to be studied.

The third comment is that sciences may be classified in either of two ways. One may consider what is studied (birds, fish, insects, and so forth) or what in each is studied (anatomy, physiology, evolution, and so on). An effort was made to cover both in the diagram, but where a choice was necessary, the

Mathematics

Natural Sciences

ASTRONOMY

Astrophysics

PHYSICS

Mechanics—*Mechanical Eng.*
Hydrodynamics—*Aeronautical Eng. & Ship Design*
Sound—*Acoustical Eng.*
Light & Optics—*Illuminating Eng.*
Heat—*Steam Engineering, etc.*
Electricity & Magnetism—*Electronics & Electrical Eng.*
Nuclear Physics—*Nuclear Eng.*

Physical Chemistry

CHEMISTRY

Inorganic Chemistry—*Chemical Engineering*
Organic Chemistry
Metallurgy—*Metallurgical Eng.*

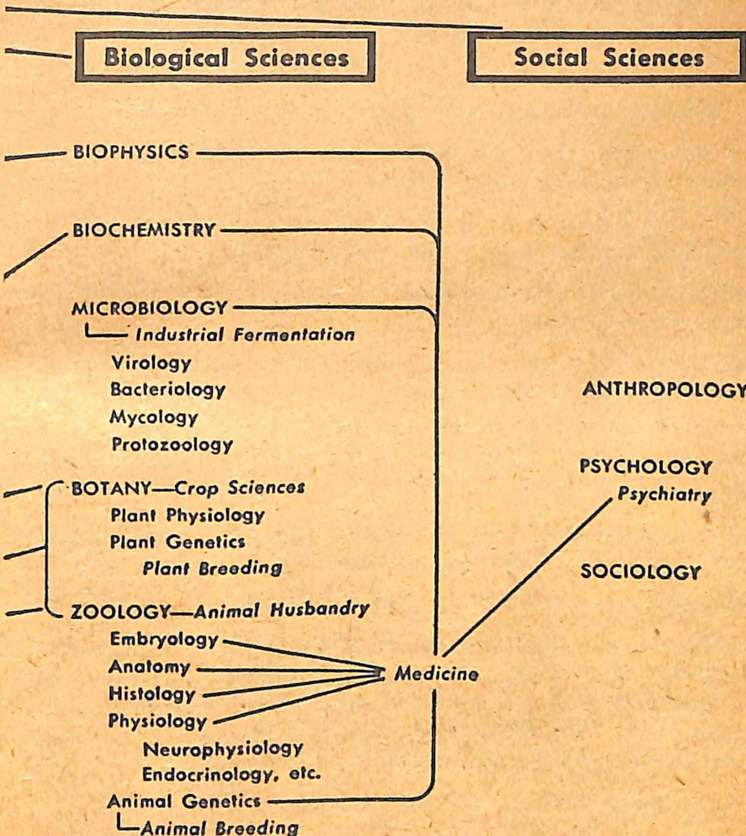
Paleontology
Ecology

GEOLOGY AND EARTH SCIENCES

Geophysics
Geochemistry
Mineralogy
Geography
Oceanography

Mining Eng.

THE FAMILY TREE


Biological Sciences
Social Sciences
BIOPHYSICS
BIOCHEMISTRY
MICROBIOLOGY
Industrial Fermentation
Virology
Bacteriology
Mycology
Protozoology
BOTANY—Crop Sciences
Plant Physiology
Plant Genetics
Plant Breeding
ZOOLOGY—Animal Husbandry
Embryology
Anatomy
Histology
Physiology
Neurophysiology
Endocrinology, etc.
Animal Genetics
Animal Breeding
Medicine
ANTHROPOLOGY
PSYCHOLOGY
Psychiatry
SOCIOLOGY

OF SCIENCE

second method of classification was used.

Finally, here are brief definitions of the less familiar terms used in the diagram, in their order in the diagram:

Astrophysics—application of laws of physics to study of stars.

Hydrodynamics—study of flow of gases and liquids and movement of bodies through gases and liquids.

Physical Chemistry—application of laws of heat and other physical laws to study of chemical reactions.

Inorganic Chemistry—chemistry, except for chemistry of compounds of carbon.

Organic Chemistry—chemistry of compounds of carbon. So called because it was once believed only living organisms could form carbon compounds.

Geophysics and *geochemistry*—study of physics and chemistry of the earth's crust.

Biophysics—study of physical processes (the optics of the eye, for example) in living organisms.

Biochemistry—the chemistry of life processes.

Microbiology—the study of microörganisms. *Virology* studies viruses; *bacteriology*, bacteria; *mycology*, yeasts and other fungi; *protozoölogy*, amoebae and other one-celled animals (protozoa). *Industrial fermentation* is the use of microbes to produce chemical products, such as antibiotics.

Paleontology—study of fossil remains.

Ecology—study of interrelation of plants, animals, and their geographical environment.

Embryology—study of growth before birth.

Histology—study of structure of tissues.

Physiology—study of how living organisms function. Particularly interesting branches of this important branch of biology include *neurophysiology* (study of the working of the nervous

system) and *endocrinology* (study of hormones).

Genetics—the science that deals with heredity.

Psychology—study of behavior. Its chief application is in *psychiatry*, the treatment of ills of the mind.

J. BRONOWSKI

The Common Sense of Science

In the previous selection, we took a look at the world that science deals with and at the family tree of science. Here, science is examined from another point of view by the prominent British physicist J. Bronowski. Science, Dr. Bronowski points out, is a human activity. As such, it has features in common with other human activities. But it also has unique features that have made it an activity apart from other human activities and of especial importance to man.

The article below is condensed from a chapter in a book of the same name by Dr. Bronowski, published in the U.S. by the Harvard University Press. It is used with Dr. Bronowski's permission, and with the permission of the Harvard University Press, Cambridge 38, Mass.

Dr. Bronowski, who is chief physicist of the British Coal Board, is one of the most articulate and eloquent of English writers on science. What makes this remarkable is the fact that English is not his native tongue. Like his fellow-countryman Joseph Conrad, who likewise achieved distinction as a writer and who also came to England at about the same age, Dr. Bronowski was born in Poland and did not come to England until he was twelve years old.

In using the word observation, I am conscious still of having drawn too passive a picture of the process of science. We may be tempted still to think of the world as going its mighty way and merely impressing on the scientist in passing a glimpse from time to time of its imperturbable motion. This would be

a grave misunderstanding. Indeed it would perpetuate the breach between the world and the experimenter which I have been trying to close. Science is not only rational; it is also empirical. Science is experiment; that is, orderly and reasoned activity. The essence of experiment and of all science is, that it is active. It does not watch the world, it tackles it.

This of course is not peculiar to science. All living is action, and human living is thoughtful action. If this is plain enough as a statement about living, it still needs to be underlined about science: that science is a characteristic activity of human life. The characteristic of human action is that it is a choice at each step between what are conceived to be several alternative courses open to us. Men can visualize these alternatives and animals probably cannot; but in both, action means choice—and this whether we suppose the choice to be free or circumscribed. In both, action is directed toward the future. Men are conscious of this direction, and choose one action rather than another in the conscious hope that it will lead to one rather than another kind of future. I add that this statement describes what they do correctly, whether we think that their choice is free or determined.

This seems to me the most important point which I can make; and oddly enough, it has had least attention in the past. The characteristic of living things is that their actions are directed toward the future. We could put this more bluntly, and say that it is simply the characteristic of action; but this seems to me a needless abstraction, since action and living are in effect interchangeable notions. Living things change; they are different tomorrow from what they were today; and their actions today are directed toward tomorrow. The enzymes in the cell are unaware that what they do will make the cell divide in twenty minutes from now; but if they fail to do it, neither they nor the cell has a future; both die. We do not know what sets in motion the life cycle of the threadworm or the liver-fluke or the oak; but we know that each stage of that cycle is a getting ready for the next; and if the organism misses one cue, it dies. The mechanism of getting ready is odd and elaborate: we see the shadow and close our eyes, we hear a noise and our glands squirt adrenalin into our blood, so that the pulses quicken, the muscles

tense, and the nerves are alert. But in every case our actions are directed toward some obscurely foreseen future. And this is true of the most primitive cell, and of Gibbon mining mountains of scholarship for the pleasure at last of minting one ringing footnote.

All this is hidden in the process of life; but it becomes plain and explicit when we look for scientific laws. For of course a scientific law is a rule by which we guide our conduct and try to ensure that it shall lead to a known future. The law formulates our anticipation of the future in a systematic way, as a kind of shorthand. And the wider the conditions in which the law applies, and the more compact as it were its shorthand, the more powerful and remarkable we think the law. But a scientific law differs from our own habitual way of pointing our actions toward the future only in being more systematic and explicit . . .

The fundamental ideas which I have been putting forward are these. Every living action is an act of choice. It is directed toward the future. The machine which we conceive within it is a predictor, which interprets past and present information as signals to accommodate itself to an expected future. And interpretation and accommodation cannot be made altogether free from error, for error is essential to the process of learning which directs them.

There is in all this a bold analogy between the way in which individuals learn, the way in which species adapt themselves, and the way in which science works. But, of course, it is my point that this is not merely an analogy: it is a true and close relation. For science is not a special activity. It is a type of all human activity. An Italian who goes to New York soon learns to adapt his habits to eating a factory-made cereal for breakfast. There is some evidence that the cereal eaters, as a species, are adapting their jaws to their diet by the slow workings of natural selection. But between these extremes there lies the equally human activity of scientific development. The invention and popularization of the breakfast cereal is itself a scientific solution to a complex of problems, which range all the way from cutting down the time between getting out of bed

and catching the train, to the full use of the most readily won foods of North America.

What marks out science as a system of prediction and adaptation from those of the individual and of the species is at bottom this, that it is a method which is shared by the whole society consciously and at one time. This at once implies that science must be communicable and systematic. Both the signals and the predictions must be of a kind which everyone can have in common. To my mind, philosophers put the cart before the horse when they say that science constructs a world by sorting out what the experiences of different people have in common. On the contrary, the practice of science supposes the existence of a real and a common world, and assumes that its impact on each individual who is part of it is modified by him in a way which constitutes his personal experience. We do not construct the world from our experiences; we are aware of the world in our experiences. Science is a language for talking not about experience but about the world.

But what is most striking about the predictions of science is that they are not an assembly of piecemeal guesses. Science is a way of ordering events: its search is for laws on which to base the single predictions. This is the stroke which rounds our picture: that science is systematic in method because it seeks a system of prediction. The aim of science is to order the particular example by articulating it on a skeleton of general law.

Once again, what I have said about science is not peculiar to it. All human conduct is shaped by what the individuals believe to be general laws. The human predictor interprets the signal by an act of recognition which puts it into some general category. We then assume that the future will have some general likeness with futures we have met before which followed this kind of signal, and this is the kind of future we prepare for. We recognize a pair of dumbbells and brace ourselves to lift them; when they turn out to be made of cardboard, the shock is unpleasant because unexpected. What is odd about the generalizations of science is not even that they are far wider, and cover a range of facts beyond the habits of any one individual. This is a real difference, but it is not the essential difference.

The essential difference is that the generalizations of science are explicit. And this derives at once from the fact that science is communicated.

The individual need never make a list of his habits, that is his generalizations, because he does not need to pass them on to anyone else. He will form habits of anticipating the future from present signals even if he never expects to meet another person. Robinson Crusoe did so; and Defoe shows striking psychological insight when he describes the disorder into which Crusoe was thrown when he saw the footprint, not because Crusoe feared the presence of other people, but because their presence had ceased to be part of his conceptual world. Although we cannot be sure, it is likely that some animals lack any form of communication; yet it is certain that they still form habits.

It is the explicit character of its laws which makes science a different activity; and this character derives from communication. Science is the activity of learning by a whole society, even though that society may so divide its labor that it passes the responsibility for this activity to a few men. And the laws of science are those principles of prediction and adaptation to the future which apply to the whole society, and can be learned by all its members in explicit form. . . .

WALTER B. CANNON

Gains from Serendipity

In investigating nature, the scientist often has a pretty good idea of what he is looking for and ultimately discovers. For instance, when Mendeleev devised the periodic table of the elements, there were gaps in the table that obviously belonged to elements then unknown. From the table, it was possible to predict what they were and even, in a general way, what their properties would be. A systematic search was made for them, and they were found. Since science is essentially a voyage into the unknown, however, many discoveries are bound to be more or less unexpected. In "Gains from Serendipity, Dr. Walter B. Cannon discusses the role of unexpected discovery in scientific advance.

"Gains From Serendipity," which appears here in slightly abridged form, is on the way to becoming a scientific classic. It is a chapter in Dr. Cannon's autobiographical memoir, *The Way of an Investigator*, published by W. W. Norton & Co., Inc., in 1945, the year Dr. Cannon died, and is reprinted with their permission. Dr. Cannon was dean of American physiologists. From his laboratory at the Harvard Medical School came, for forty years, a steady stream of important discoveries concerning the ductless glands, surgical shock, and many other aspects of physiology. He was also widely known as an able and engaging lecturer and writer.

In 1754 Horace Walpole, in a chatty letter to his friend Horace Mann, proposed adding a new word to our vocabulary, "serendipity." The word looks as if it might be of Latin origin. It is

rarely used. It is not found in the abridged dictionaries. When I mentioned serendipity to one of my acquaintances and asked him if he could guess the meaning, he suggested that it probably designated a mental state combining serenity and stupidity—an ingenious guess, but erroneous.

Walpole's proposal was based upon his reading of a fairy tale entitled *The Three Princes of Serendip*. Serendip, I may interject, was the ancient name of Ceylon. "As their highnesses traveled," so Walpole wrote, "they were always making discoveries, by *accident* or *sagacity*, of things which they were not in quest of." When the word is mentioned in dictionaries, therefore, it is said to designate the happy faculty, or luck, of finding unforeseen evidence of one's ideas or, with surprise, coming upon new objects or relations which were not being sought.

Readers who remember Bible stories will recall that Saul, the son of Kish, was sent forth to find his father's asses, which were lost. In the discouragement of his failures to find them he consulted one Samuel, a seer. And Samuel told him not to set his mind on them for they had been found, but to know that he was chosen to rule over all the tribes of Israel. So it was announced, and the people shouted their approval. Thus modest Saul, who went out to seek lost asses, was rewarded by a kingdom. That is the earliest record of serendipity I am aware of.

Probably the most astounding instance of accidental discovery in either ancient or modern history was the finding of the western hemisphere by Columbus. He sailed away from Spain firm in the faith that by going west he would learn a shorter route to the East Indies; quite unexpectedly he encountered a whole new world. It is noteworthy that he was not aware of the significance of what he had found. Indeed, it has been said that he did not know where, in fact, he was going nor where he was when he arrived nor where he had been after his return, but nevertheless he had had the most unique adventure of all time. He realized that he had had a remarkable experience and, by extending the knowledge of what he had done, he laid a course which others might follow. Such consequences have been common when accident has been favor-

able to one engaged in a search and the enterprise has proved fruitful.

In the records of scientific investigation this sort of happy use of good fortune has been conspicuous. A good example is afforded by the origin and development of our acquaintance with electrical phenomena. It is reported that some frogs' legs were hanging by a copper wire from an iron balustrade in the Galvani home in Bologna; they were seen to twitch when they were swung by the wind and happened to touch the iron. Whether the twitching was first noted by Luigi Galvani, the anatomist and physiologist, or by Lucia Galvani, his talented wife, is not clear. Certainly that fortuitous occurrence late in the eighteenth century was not neglected, for it started many researches which have preserved the Galvani name in the terms "galvanize" and "galvanism." And it also led to experiments by his contemporary, Volta, on the production of electric currents by contact of two dissimilar metals—and thus to the invention of the electric battery—experiments so fundamentally important that Volta's name is retained in the daily use of the words "volt" and "voltage."

Such were the accidental beginnings of the telegraph and indirectly of the telephone, radio-broadcasting, and the promise of practical television. And such also were the beginnings of our knowledge of animal electricity. We now use it, for example, to indicate the disordered state of the heart, because every cardiac contraction sends forth through our bodies an electrical wave, a wave that has a different shape according to the damage in the heart muscle. Only recently have we begun to employ animal electricity to give us information about conditions in the brain. That marvelous organ composed of many billions of nerve cells can display rhythmic electrical pulsations and, when extremely delicate instruments are applied to the scalp, they can reveal the different types of pulsations in rest and activity and the modification in some states of disease. . . .

In the biological sciences serendipity has been quite as consequential as in the physical sciences. Claude Bernard, for example, had the idea that the impulses which pass along nerve fibers set up chemical changes producing heat. In an experi-

ment performed about the middle of the last century he measured the temperature of a rabbit's ear and then severed a nerve which delivers impulses to that structure, expecting, in accordance with his theory, that the ear deprived of nerve impulses would be cooler than its mate on the other side. To his great surprise it was considerably warmer! Without at first knowing the import of what he had done, he had disconnected the blood vessels of the ear from the nervous influences that normally hold them moderately contracted; thereupon the warm blood from internal organs was flushed through the expanded vessels in a faster flow and the ear temperature rose. Thus by accident appeared the first intimation that the passage of blood into different parts of the body is under the government of nerves—one of the most significant advances in our knowledge of the circulation since Harvey's proof, early in the seventeenth century, that the blood does indeed circulate in the vessels.

Another striking instance of accidental discovery has been described by the French physiologist, Charles Richet, a Nobel laureate. It was concerned with a peculiar sensitiveness toward certain substances—such as white of egg, strawberries, ragweed pollen and numerous others—that we now speak of as *anaphylaxis* or *allergy*. This may result from an initial exposure to the substance which later becomes poisonous to the victim. The phenomenon had been noticed incidentally before Richet's studies, but because it did not receive attention its characteristics were virtually unknown. In his charming little book *Le Savant,* he has told the story of how quite unexpectedly he happened upon the curious fact. He was testing an extract of the tentacles of a sea anemone on laboratory animals in order to learn the toxic dose. When animals which had readily survived that dose were given after a lapse of some time a much smaller dose (as little as one-tenth), he was astounded to find that it was promptly fatal. Richet declares that at first he had great difficulty in believing the result could be due to anything *he* had done. Indeed, he testified that it was in spite of himself that he discovered induced sensitization. He would never have dreamed that it was possible.

Pasteur was led by chance to his method of immunization.

One day an old and forgotten bacterial culture was being used for inoculating fowls. The fowls became ill but did not die. This happening was illuminative. Possibly by first using cultures that had little virulence and then repeating the injections with cultures of greater virulence, the animals could be made to develop resistance to infection gradually. His surmise proved correct. By this procedure, as readers of his dramatic biography will remember, he was able to immunize sheep against anthrax and human beings against rabies.

It was an accidental observation which ultimately resulted in the discovery of insulin and the restoration of effective living to tens of thousands of sufferers from diabetes. In the late eighties of the last century, Von Mering and Minkowski were studying the functions of the pancreas in digestion. While attempting to secure more evidence they removed that organ from a number of dogs. By good luck a laboratory assistant noticed that swarms of flies gathered round the urine of these animals, a fact which he mentioned to the investigators. When the urine was analyzed, it was found to be loaded with sugar. Thus for the first time experimental diabetes was produced, and the earliest glimpse was given into a possible cause of that disease. . . .

An unforeseen contingency may occasion scientific advances because of the serious problem it presents. A striking instance is afforded in the use of polished rice. There was no reason to anticipate that the polishing of rice would be harmful to those who depended upon it as a food. Yet removal of the covering from the kernels produced in myriads of victims the disease beriberi, resulting in immeasurable sorrow and distress. As has been pointed out, however, the study of beriberi, thus unwittingly induced, disclosed not only the cause of that disorder but also started explorations in the whole realm of deficiency diseases and thus led to the discovery of some of the most intimate secrets of cellular processes. . . .

In the life of an investigator whose researches range extensively, advantages from happy chance are almost certain to be encountered. During nearly five decades of scientific experimenting instances of serendipity have several times been my good fortune. Two experiences I mention elsewhere, but

not in relation to serendipity. One was stoppage of the movements of the stomach and intestines in times of anxiety. The other was the strange faster beating of the heart, after all its governing nerves were severed, if the animal became excited or if sympathetic fibers were stimulated in some remote region of the body. This effect, due to an agent carried to the heart by the circulating blood, led to the discovery of *sympathin*. Both phenomena were quite unexpected. Proof that the stoppage of digestive movements was due to emotion was the beginning of many years of research on the influence of fear and rage on bodily functions. And the unraveling of the mystery of sympathin led ultimately to prolonged studies on the chemical mediator that serves to transmit influences from nerve endings to the organs they control. . . .

Three legends of accidental leads to fresh insight serve to introduce the next point, which is quite as important as serendipity itself. I refer to the presence of a prepared mind. It is said that the idea of specific gravity came to Archimedes as he noted by chance the buoyancy of his body in water. We have all heard the tale, illustrative even if not authentic, that the concept of a universal law of gravitational force occurred to Isaac Newton when he saw an apple fall from a tree while he lay musing on the grass in an orchard. Of similar import is the story that the possibility of the steam engine suddenly occurred to James Watt when he beheld the periodic lifting of the lid of a tea kettle by the steam pressure within it. Many a man floated in water before Archimedes; apples fell from trees as long ago as the Garden of Eden (exact date uncertain!); and the outrush of steam against resistance could have been noted at any time since the discovery of fire and its use under a covered pot of water. In all three cases it was eons before the significance of these events was perceived. Obviously a chance discovery involves both the phenomenon to be observed and the appreciative, intelligent observer.

I may now add to these legends and their illustrative significance the history of that marvelously powerful enemy of infection, penicillin. In 1929 the English bacteriologist, Alexander Fleming, reported noticing that a culture of pus-producing bac-

teria underwent dissolution in the neighborhood of a mold which accidentally contaminated it. This was the pregnant hint. A careless worker might have thrown the culture away because of the contamination. Instead, Fleming let the mold grow in broth and thus learned that there passed into the broth from the mold a substance which was highly efficacious in stopping the growth of a wide range of disease-producing germs and destroying them. Furthermore he learned that, when injected, this substance was not itself harmful to animals. The mold, a variety of *Penicillium,* suggested the name "penicillin." The long struggle of Howard Florey and his associates at Oxford in purifying and standardizing this highly potent agent and in proving its value in human cases cannot be recounted here. The record, however, reports one of the most striking instances of immense value that can result from a combination of chance and an alert intelligence; and shows how a brilliant discovery is made practical by hard labor.

Long ago Pasteur recognized that when accident favors an investigator it must be met by sharp insight, for he uttered the wise and discerning dictum, *"Dans les champs de l'observation, le hasard ne favorise que les esprits préparés."* Even before Pasteur, Joseph Henry, the American physicist, enunciated the same truth when he said, "The seeds of great discoveries are constantly floating around us, but they only take root in minds well prepared to receive them."

2. The Earth and the Universe

GEORGE GAMOW

The Origin and Evolution of the Universe

Professor George Gamow of George Washington University is not only a theoretical physicist of the first rank, but one of the ablest writers on science in the English language. His many enormously successful books include *The Birth and Death of the Sun, Atomic Energy in Cosmic and Human Life* and the several adventures of Mr. Tompkins (one of which is quoted from elsewhere in this volume). The interesting point (as most of Dr. Gamow's writings plainly show) is that English is not Dr. Gamow's native language. He was born in Russia and came to the United States only in 1934, at the age of thirty.

The article below is condensed slightly from a lecture given by Dr. Gamow at a number of universities in 1950 and 1951 under the auspices of Sigma Xi, a scientific society that sponsors a distinguished series of lectures each year. Recent advances in astronomy necessitate only one change in the lecture (which is reprinted with the permission of Dr. Gamow, the *American Scientist* and the Society of Sigma Xi). Dr. Gamow gives the age of the universe, as calculated from its size, as 1.8 billion years. In 1952, it was found that the universe is twice as large as was believed. Hence, its age, as calculated from its size, is over twice as great, or roughly 5 billion years—a figure that agrees much better than 1.8 billion years given in the original lecture with other estimates of the universe's age.

The problem of the origin of the world has been occupying human minds ever since the dawn of history. All ancient re-

ligions, which were essentially the first attempts of awakening intellect to find its place in the surrounding world, discussed the problem of creation at considerable length. Some of them even went so far as to give the exact date of the "creative act." Thus Archbishop Ussher, in the seventeenth century, concluded from the narratives of the Old Testament that the world was created in the year 4004 B.C. Much more elaborate calculations by the occult scientists of ancient India led to the date which would make the world 1,972,949,052 years old as of today. Modern estimates, based on detailed studies of various evolutionary features of the universe, do not claim the precision of the ancient thinkers, but they all agree that the zero point of the history of the universe must be placed at a few billion years ago.

There are two different geological methods for estimating the date when the earth was formed: one of them leads to the age of the oceans, the other to the age of the continents. We can get a fair idea concerning the age of oceans by studying the salinity of ocean water. This water contains about three per cent of dissolved salts, which, if extracted and piled upon the land, would cover the area of the United States by a layer almost two miles thick. How did all this salt come into the ocean? Strange as it may sound at first, salt is being brought into the oceans by the rivers, which wash it away from the rocks forming the crust of the earth. While water evaporates from the ocean surface, and falls again on the continents to repeat its eternal cycle, the dissolved salt stays in and gradually increases the salinity of ocean water.

Geologists estimate that every year the rivers bring into the ocean about 400,000,000 tons of salt. Since the present amount of ocean salt is 40,000,000,000,000,000 tons, the process must have lasted for at least 100,000,000 years. This figure must be increased by a factor of a few tens, since it is known that at the present epoch the erosion of continents is abnormally high, and that during most of the geological time (when there were much fewer mountain ranges than now) the erosion was only a small fraction of its present value. Thus, the fact itself that the oceans are not saturated with salt proves that they could have existed only for a limited period of time, while the date of

their formation may be set at a few billion years ago.

The age of the continents can be estimated by measuring the age of various rocks from which they are formed. It is known that many rocks contain small deposits of radioactive elements, uranium and thorium, which are slowly decaying into lead. Once the rock is solidified from the originally melted state, this radiogenic lead stays together with the original radioactive elements. Therefore, by measuring the uranium/lead and thorium/lead ratios, we can get a rather exact figure for the age of a given rock, in the same way as one can find how long a furnace was burning by comparing the amounts of remaining coal and accumulated ashes. Using this method, one finds different ages for the rocks of different geologic formations, with the maximum value four to five billion years. We can consider this figure as the lower limit, and possibly as a good actual value for the age of the earth. . . .

Astronomers have essentially three different methods for judging the age of the stellar universe. The first is based on the study of stellar motion within our system of the Milky Way, and refers to the statistical distribution of stellar velocities which is expected to approach a certain "limiting distribution" (the so-called equipartition of energy between all stars) when the stellar system has existed for a sufficiently long time. The observed velocity distribution is still some way off from that "limiting distribution," which, according to mathematical calculations, indicates that the system must have existed for only a few billion years.

The second astronomical method is based on the study of stellar energy sources. We know in fact that stars, and in particular our sun, derive their energy from the slow nuclear transformation of hydrogen into helium taking place in their hot central regions. Thus, the natural life span of a star is determined by the rate of its burning (that is, by its absolute brightness) and by the original amount of hydrogen it contains. Since the brightness of stars is known to increase as the cube of their mass, and the amount of nuclear fuel is simply proportional to the mass (hydrogen forms about half of the total mass in a normal star), the brighter stars will burn out faster than fainter ones, their life span being inversely proportional

to the square of their mass. Our sun is a comparatively faint star; its total life span can be calculated to be about ten billion years. If the sun is only a few billion years old, it may be compared with a young man just in adulthood.

The stars which are about 40 per cent heavier than the sun burn twice as fast and have a life span of only about five billion years. Observational astronomy reveals that the stars of just about that mass seem to be on the verge of hydrogen exhaustion. The dwindling of their fuel supply is manifested in all kinds of "unquiet behavior" ranging from regular pulsations of their giant bodies (Cepheid variables) to terrific explosions (novae and supernovae) which tear these stars apart. It therefore seems reasonable to conclude that most of the stars forming the system of the Milky Way were originally formed about five billion years ago, and that in the case of pulsating and exploding stars we observe the death agony of those members of the stellar community who are coming to the end of their natural life during the present epoch of the history of the universe.

The third astronomical method of estimating the age of the universe is based on the phenomenon of universal expansion discovered by the Mount Wilson astronomer, E. Hubble, about a quarter of a century ago. We know that the stellar system of the Milky Way, containing our sun along with several billions of other stars, is not a lonely island in the infinite expanses of the universe. Large telescopes reveal that the space outside our galaxy is populated by myriads of similar stellar systems scattered more or less uniformly all the way to the limit of telescopic vision.

There are nearly one billion such galaxies within the range of the 200-inch telescope of the Palomar Mountain Observatory, and the author was told by Professor Harlow Shapley of Harvard that whenever he has a new graduate student he sends him up to the telescope with orders "to discover a new galaxy and to name it." The striking thing about these distant galaxies of stars is that the light emitted by them, while similar to the light coming from nearby galaxies, shows however the peculiar phenomenon of a shift of all spectral lines toward the red end of the spectrum. A simple physical explanation of this "red

shift" lies in the assumption that the galaxies are receding from us at rather high speeds. This so-called Doppler effect, consisting of the change in frequency of waves emitted by an approaching or receding source, is a familiar phenomenon in the field of acoustics. Everyone has noticed how the aggressive high-pitched honk of an approaching, fast-driven car goes into a much lower departing tune as the car passes by.

In optics the same effect will make the light of an approaching source look bluer and that of a receding source redder than it actually is. There is a story of how this Doppler effect in optics almost saved the famous American physicist, R. W. Wood, from paying the usual fine for crossing an intersection on a red light. The story goes that, being summoned to the traffic court with the violation ticket, Professor Wood gave a brilliant (as usual) lecture to the judge on the subject of the Doppler effect, explaining how and why one can see a red light as green if one drives toward it. But, while the judge was highly impressed by that presentation, and was ready to waive the fine, one of Wood's students (recently flunked by him on an optics examination) happened to be in the courtroom and proposed that the judge ask the professor to estimate the velocity with which he must have been driving in order to see the red light as green. As a result, the fine was changed from that for crossing on a red light to that for exceeding the speed limit of the city of Baltimore.

Hubble's measurement of the red shift in distant galaxies indicates that they all move away from us with speeds proportional to their distances. It does not mean, however, that we actually are in the center of the universe with all its parts running away from us, and can, in fact, be interpreted simply as an optical illusion common to *any* observer located *anywhere* within a uniformly expanding system. If we imagine an inflated rubber balloon with black dots painted all over its surface in a polka-dot fashion (the galaxies scattered through the space of the universe), an observer sitting on *any one* of these dots will see all other dots receding from him when the balloon is gradually swelling to a larger and larger size. And the observed recession-velocity of more distant dots will be larger in proportion to their distances.

The observationally established expansion of the universe gives us a valuable clue to the history of the universe, indicating that all present features of the universe must have originated as the result of successive differentiation of a rapidly expanding primordial matter. The date of the "beginning," that is the epoch when the material forming the universe was in the original highly compressed homogeneous state, can be obtained by a simple division of the average distance between the neighboring galaxies by the measured velocity of their mutual recession. The result, five billion years, is of the same order of magnitude as all other approximate estimates of the age of the universe. . . .

The Formation of Atomic Species

When we inquire about the early stages in the history of the universe, we find that the most valuable archaeological document is presented by the relative abundance with which different atomic species are found in nature. In fact, there is every reason to believe that chemical elements were "cooked" very early in history when the density and temperature of the matter in the universe were both exceedingly high. If we imagine history running back in time, we inevitably come to that epoch of "big squeeze" with all the galaxies, stars, atoms, and atomic nuclei squeezed, so to speak, to a pulp.

During that early stage of evolution, matter must have been dissociated into its elementary components: protons, neutrons, and electrons. We called this primordial mixture *ylem* since in *Webster's Dictionary* this word is explained as: "O.F. *ilem*, fr. L. *hylem*, acc. of *hyle*. See Hyle. The first substance from which the elements were supposed to be formed. Cf. Hyle, 1. *Obs.*" While the temperature of ylem was still very high (above one billion degrees Centigrade) thermal motion of the particles was too violent to permit their sticking together. This high temperature also prevented neutrons from decaying into protons and electrons, or, to state it more correctly, the production of fresh neutrons in the processes of proton-electron collisions at that time was compensating for their loss due to the decay process.

However, as soon as the density and temperature of matter dropped as the result of the progressing expansion, two processes must have started. The first process was the predominating neutron decay which was cutting sharply into the number of neutrons available for the nuclear reaction. The second was the aggregation of neutrons and protons into complex groups: the prototypes of the atomic nuclei of today. The result of the competition between these two processes must have determined the relative numbers of various composite nuclei which exist in nature at the present time. If the expansion had been too fast or the original density of matter too low, very few nuclear collisions could have taken place before all neutrons were destroyed (turned into protons) by the natural decay process. In this case, practically no complex nuclei would have been built, and the matter of the universe today would consist predominantly of hydrogen. If, on the contrary, the original density had been too high, neutrons and protons would have had ample chance to unite into complex units, and most of the material of the universe would be present now in the form of heavier elements.

Apparently, the actual situation was somewhere between these two extremes, and we should be able to get rather exact information concerning the physical conditions which prevailed during the early stages of the expansion of the universe, by analyzing in detail the processes of nuclear formation which took place during that epoch. It must be remembered that, even though these processes occurred billions of years ago, we can discuss them on the basis of perfectly reliable nuclear information. In fact, the temperature of a billion degrees corresponds to thermal energies of the order of one million volts, and these are exactly the energies at which nuclear reactions are being studied in our laboratories using electrically accelerated nuclear beams.

The first attempt to calculate what must have happened to ylem during the early stages of the expanding universe was made by the author and a former student, R. Alpher, several years ago. The problem presented by the building-up process of atomic nuclei is very similar to the classical problem of heat flowing along a bar heated at one end. In the latter problem

the increase of temperature in any section of the bar is given by the difference between the heat inflow from the heated side and the heat outflow in the opposite direction. Similarly, the increase in the number of representatives of any given nuclear species, say the nuclei with atomic weight 100, is given by the difference between the rate of their production through neutron capture in 99-weight and their elimination as the result of moving into 101-weight through a subsequent neutron capture.

One can write simple differential equations containing the known neutron-capture cross sections, the solution of which will give us the expected distribution of the original material between different atomic weights, for any given original density and any given time of cooking. Since, as was stated above, the expansion process must have started spontaneous decay of neutrons, the entire "cooking period" could not have lasted much longer than the mean lifetime of a free neutron (the order of magnitude of half an hour). It may look silly to talk about the consequences of a process which took place five billion years ago and lasted for only half an hour, but the ratio of half an hour to a few billion years is about the same as the ratio of a few microseconds to several years, which represent respectively the reaction time within an exploding atomic bomb and the period of time after which the radioactivity of fission products can still be noticed at the explosion site! . . .

The First Thirty Million Years, and the Beginning of the Differentiation Process

After atomic species were formed in the first half-hour or so of the history of the universe, the expansion of newly formed matter continued in a rather monotonous way for quite a long time. The most characteristic feature of this entire period was the prevailing role of radiant energy as compared with ordinary matter. It is well known that, according to Einstein's law, radiant energy possesses ponderable mass, the value of which can be obtained numerically by dividing the amount of energy, expressed in ergs, by the square of the velocity of light. Using this rule, we can easily find, for example, that the light which is filling a lecture room weighs only a few

billionths of a microgram—about the weight of one bacterium! This is, of course, a negligibly small figure as compared with the weight of the air in the same lecture room.

If, however, we make a similar calculation for radiant energy and ordinary matter during the early stages of the expansion of the universe, we shall arrive at a rather different result. Assuming that at the end of five minutes the temperature of the universe was about one billion degrees (as it follows from the previous discussion), we find that the mass density of radiation . . . was about 10 gm./cm.^{3} thus being comparable with the density of iron! Since, at the same time, the density of ordinary (atomic) matter was only about one microgram per cubic centimeter, we conclude that at that epoch the situation was ruled exclusively by light (with very short wave length, of course) and that the material particles were helplessly thrown around like little chips of wood in the stormy ocean of radiation.

As the expansion of the universe proceeded, the situation was gradually changing in favor of matter. Indeed, whereas the total number of atoms was left unchanged, radiant energy was being spent doing the work of expansion. It can be calculated that the density of matter and radiation became equalized approximately at the age of about 30,000,000 years, when the temperature of the universe dropped to about 300° Kelvin (roughly room temperature), and its material density to the value of about 10^{-24} gm./cm.^{3} (one hydrogen atom per cm.^{3} or the present density within the galaxy).

At that point in history, matter took over the leading role in further developments, and its first deed was to break up the homogeneity of the hitherto continuous expansion process. The chief agent in this breaking-up process, which ultimately led to the present highly differentiated state of the material universe, was Newtonian gravitation between material particles. In fact, as it was once shown by the British astronomer, Sir James Jeans, a gravitating gas filling uniformly an unlimited space is intrinsically unstable, and is bound to break up into separate "gas balls" with completely empty space in between. . . .

When, at the date mark of 30,000,000 years, the originally homogeneous gas broke up into [these] separate clouds (the

progenitors of today's galaxies), the space of the universe was quite dark since the original brilliance of the first days of creation was already dimmed out by expansion, and the stars, which illuminate the universe today, were not yet formed. There was nothing at that time but giant clouds of lukewarm gas which were being pulled away from each other by the progressing expansion of space. It goes without saying that the break-up of the expanding gas into separate clouds, or fragments, must have resulted in a rather rapid rotation of these fragments around their axes distributed at random in all directions. We observe the same type of rotation in the fragments of an artillery shell exploded in mid-air. Here probably lies the explanation of the fact that most galaxies are found now in the state of rotation, manifested in their flattened elliptical shapes and in their spiral arms winding around their centrally condensed bodies.

Stars, Planets, Satellites

The next step in the evolution of the universe apparently was the formation of stars, which must have originated as the result of the secondary condensation, that is the break-up of the original "galactic gas balls" into billions of smaller "stellar gas balls" by the same old process of gravitational instability. These smaller gas condensations contracted quite rapidly, and, as the result of compression, the material in their central regions was heated to the temperature of some 20,000,000 degrees, representing the threshold for nuclear reactions. The liberation of nuclear energy had started, and the universe became illuminated by billions and billions of stars.

Space does not permit us to consider here the detailed analysis of stellar evolution, and, in particular, the problem of the origin of planetary systems. We shall mention only that, according to recent theories of the German physicist, C. von Weizsäcker, and the American astronomer, G. P. Kuiper, the formation of the planets took place in a way very similar to that proposed centuries ago by Kant and Laplace (the collision theory of Jeans, and Chamberlin and Moulton, being abandoned by modern cosmogony). Since, as was mentioned

above, the material forming the original galactic gas balls was in a state of rapid turbulent rotation, stellar condensations (or pre-stars) were rotating too. Thus, whereas most of their material must have fallen toward the center, forming the main body of the star, some of it must have been left outside in the form of a strongly flattened or rotating disk. About ninety-nine per cent of this disk was gaseous hydrogen and helium, whereas the remaining one per cent was formed by small dust particles of silicates, iron oxides, ice crystals, etc.

The dust particles of that swarm must have been always colliding with one another. . . . Those chunks of the material which happened to grow larger than the others swept the space around them, capturing the smaller stones and dust particles, until they found themselves moving in practically empty space. . . .

There is one more important point to be mentioned in connection with the theory of planetary origin. As we have seen above, planets were formed by the accumulation of solid dust particles which were floating in a hydrogen-helium gaseous mixture. Such a process would produce rocky bodies similar to our earth, to Mars, and to two internal planets: Venus and Mercury. However, if the mass of a planet exceeded certain limits (a few earth masses), it would possess a sufficiently strong gravitational field to capture and hold quite large amounts of interstellar hydrogen and helium gases. Neither our earth nor the three other inner planets ever exceeded that limit, and so they have remained rocky bodies as we know them now. On the other hand, the original rocky bodies of outer planets, such as Jupiter and Saturn, managed to grow above that limit (because the original dust disk was thicker at these distances), and thus have acquired a lot of interstellar gaseous material.

It was recently shown by H. Brown of Chicago that only about two per cent of the giant bodies of Jupiter and Saturn is made from the same material as our earth. This material, forming the rocky cores of these planets, is covered by layers of frozen water, methane, and ammonia, which account for another eight per cent. The rest of Jupiter and Saturn is nothing but highly compressed mixtures of gaseous hydrogen and helium. Thus, if Flash Gordon of the Sunday comic strips, or

a serious rocket explorer of the future, were to land on the seemingly solid surface of these planets, he would sink deeper and deeper into the compressed gas, and would finally be crushed by the tremendously high pressures lying deep in the body of these planets at the surfaces of their inner solid cores.

The formation of satellites took place in a way completely similar to planet formation, by the condensation of dust particles from the flattened rotating envelopes which surround the proto-planets. The only possible exception is presented by our own moon, which stands out of the company of other satellites because of its exceptionally large relative mass. It is believed that the earth was originally born without any satellites (as were Venus and Mercury), and that it was later broken into two pieces (larger one, the earth; the smaller one, the moon) by the tidal forces of the sun. In fact, a British astronomer, George Darwin, was able to show that in the distant past the moon was much closer to the earth, and that several billion years ago the earth and the moon must have comprised one single body. We may note here again that the calculated date of the moon's birth fits well with other values quoted for the age of the universe. . . .

A Glance into the Future

Having learned that the universe, as we know it today, must have originated a few billion years ago from hot homogeneous ylem which was successively differentiated in the process of expansion of the universe, we may naturally ask: What lies ahead of us? Will the universe continue its present expansion beyond any limit, or will it stop and start collapsing back on us (or rather on our descendants)? This question can be answered in a simple way by comparing the kinetic energy of galaxies flying away, with the potential energy of the Newtonian attraction between them. Using the available data, one can easily find that the kinetic energy of galactic recession is almost a hundred times as large as their mutual gravitational energy. Thus, the situation is similar to the case of a rocket fired from the surface of the earth with ten times the escape velocity (one hundred times the escape energy). The galaxies

will fly apart forever without ever turning back. Within each galaxy the process of stellar evolution will be continuing, and the stars, which draw their death ticket by using up all their hydrogen fuel, will be exploding and going into oblivion. Some 5,000,000,000 years from now, that fate will reach our own sun, and still later the other fainter stars. But all this is still so far away that it is hardly cause for anxiety.

Another question we could ask pertains to the forces which caused the initial expansion of the universe, and to the state of affairs which must have existed *prior* to the maximum stage of contraction which was the starting point of all our discussion. Mathematically we may say that the observed expansion of the universe is nothing but the bouncing back which resulted from a collapse prior to the zero point of time a few billion years ago. Physically, however, there is no sense in speaking about that "prehistoric state" of the universe, since indeed during the stage of maximum compression everything was squeezed into pulp, or rather into ylem, and no information could have been left from the earlier time if there ever was one.

This conclusion is in complete agreement with the statement made centuries ago by St. Augustine of Hippo who, in one of his writings, was trying to answer the question of what God was doing before He made heaven and earth. "He was making the hell," wrote St. Augustine, "for the persons who ask that kind of question."

BERTRAND RUSSELL

Space-Time

Over the decades, there have been innumerable attempts to explain in non-technical language the revolution in thought brought about by Albert Einstein and relativity. By all odds the best remains a short volume published in 1925, *The ABC of Relativity*, by the English mathematician, philosopher, and champion explainer of difficult subjects, Bertrand Russell. The selection below (reprinted by permission of Harper & Brothers) is a chapter from *The ABC of Relativity*. In this chapter, Lord Russell takes up what seems to most people the "queerest" aspect of relativity—the destruction of our traditional idea of time. We are accustomed to thinking of time as something existing apart from space and the material content of the universe, and as being everywhere the same. Einstein showed that this may be a serviceable enough idea as long as we are talking about the earth; but if we wish to speak of the far reaches of the universe, we need a different kind of time to make the laws of motion and other laws of physics "work."

Everybody who has ever heard of relativity knows the phrase "space-time," and knows that the correct thing is to use this phrase when formerly we should have said "space *and* time." But very few people who are not mathematicians have any clear idea of what is meant by this change of phraseology. Before dealing further with the special theory of relativity, I want to try to convey to the reader what is involved in the new phrase "space-time," because that is, from a philosophical and imaginative point of view, perhaps the most important of all the novelties that Einstein has introduced.

Suppose you wish to say where and when some event has occurred—say an explosion on an airship—you will have to mention four quantities, say the latitude and longitude, the height above the ground, and the time. According to the traditional view, the first three of these give the position in space, while the fourth gives the position in time. The three quantities that give the position in space may be assigned in all sorts of ways. You might, for instance, take the plane of the equator, the plane of the meridian of Greenwich, and the plane of the ninetieth meridian, and say how far the airship was from each of these planes; these three distances would be what are called "Cartesian co-ordinates," after Descartes. You might take any other three planes all at right angles to each other, and you would still have Cartesian co-ordinates. Or you might take the distance from London to a point vertically below the airship, the direction of this distance (northeast, west-southwest, or whatever it might be), and the height of the airship above the ground. There are an infinite number of such ways of fixing the position in space, all equally legitimate; the choice between them is merely one of convenience.

When people said that space had three dimensions, they meant just this: that three quantities were necessary in order to specify the position of a point in space, but that the method of assigning these quantities was wholly arbitrary.

With regard to time, the matter was thought to be quite different. The only arbitrary elements in the reckoning of time were the unit, and the point of time from which the reckoning started. One could reckon in Greenwich time, or in Paris time, or in New York time; that made a difference as to the point of departure. One could reckon in seconds, minutes, hours, days, or years; that was a difference of unit. Both these were obvious and trivial matters. There was nothing corresponding to the liberty of choice as in the method of fixing position in space. And, in particular, it was thought that the method of fixing position in space and the method of fixing position in time could be made wholly independent of each other. For these reasons, people regarded time and space as quite distinct.

The theory of relativity has changed this. There are now a number of different ways of fixing position in time, which do

not differ merely as to the unit and the starting point. Indeed, as we have seen, if one event is simultaneous with another in one reckoning, it will precede it in another, and follow it in a third. Moreover, the space and time reckonings are no longer independent of each other. If you alter the way of reckoning position in space, you may also alter the time interval between two events. If you alter the way of reckoning time, you may also alter the distance in space between two events. Thus space and time are no longer independent, any more than the three dimensions of space are. We still need four quantities to determine the position of an event, but we cannot, as before, divide off one of the four as quite independent of the other three.

It is not quite true to say that there is no longer any distinction between time and space. As we have seen, there are time-like intervals and space-like intervals. But the distinction is of a different sort from that which was formerly assumed. There is no longer a universal time which can be applied without ambiguity to any part of the universe; there are only the various "proper" times of the various bodies in the universe, which agree approximately for two bodies which are not in rapid relative motion, but never agree exactly except for two bodies which are at rest relatively to each other.

The picture of the world which is required for this new state of affairs is as follows: Suppose an event *E* occurs to me, and simultaneously a flash of light goes out from me in all directions. Anything that happens to any body after the light from the flash has reached it is definitely after the event *E* in any system of reckoning time. Any event anywhere which I could have seen before the event *E* occurred to me is definitely before the event *E* in any system of reckoning time. But any event which happened in the intervening time is not definitely either before or after the event *E*. To make the matter definite: suppose I could observe a person in Sirius, and he could observe me. Anything which he does, and which I see before the event *E* occurs to me, is definitely before *E;* anything he does after he has seen the event *E* is definitely after *E*. But anything that he does before he sees the event *E*, but so that I see it after the event *E* has happened, is not definitely before or after *E*. Since light takes many years to travel from Sirius to the earth, this

gives a period of twice as many years in Sirius which may be called "contemporary" with *E*, since these years are not definitely before or after *E*.

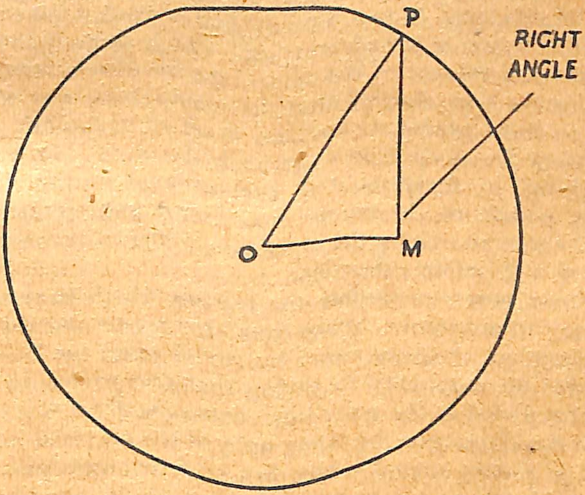
Dr. A. A. Robb, in his *Theory of Time and Space*, suggests a point of view which may or may not be philosophically fundamental, but is at any rate a help in understanding the state of affairs we have been describing. He maintains that one event can only be said to be definitely *before* another if it can influence that other in some way. Now influences spread from a center at varying rates. Newspapers exercise an influence emanating from London at an average rate of about twenty miles an hour—rather more for long distances. Anything a man does because of what he reads in the newspaper is clearly subsequent to the printing of the newspaper. Sounds travel much faster: it would be possible to arrange a series of loud-speakers along the main roads, and have newspapers shouted from each to the next. But telegraphing is quicker, and wireless telegraphy travels with the velocity of light, so that nothing quicker can ever be hoped for. Now what a man does in consequence of receiving a wireless message he does *after* the message was sent; the meaning here is quite independent of conventions as to the measurement of time. But anything that he does while the message is on its way cannot be influenced by the sending of the message, and cannot influence the sender until some little time after he sent the message. That is to say, if two bodies are widely separated, neither can influence the other except after a certain lapse of time; what happens before that time has elapsed cannot affect the distant body. Suppose, for instance, that some notable event happens on the sun: there is a period of sixteen minutes on the earth during which no event on the earth can have influenced or been influenced by the said notable event on the sun. This gives a substantial ground for regarding that period of sixteen minutes on the earth as neither before nor after the event on the sun.

The paradoxes of the special theory of relativity are only paradoxes because we are unaccustomed to the point of view, and in the habit of taking things for granted when we have no right to do so. This is especially true as regards the measurement of lengths. In daily life, our way of measuring lengths is

to apply a foot rule or some other measure. At the moment when the foot rule is applied, it is at rest relatively to the body which is being measured. Consequently the length that we arrive at by measurement is the "proper" length, that is to say the length as estimated by an observer who shares the motion of the body. We never in ordinary life have to tackle the problem of measuring a body which is in continual motion. And even if we did, the velocities of visible bodies on the earth are so small relatively to the earth that the anomalies dealt with by the theory of relativity would not appear. But in astronomy, or in the investigation of atomic structure, we are faced with problems which cannot be tackled in this way. Not being Joshua, we cannot make the sun stand still while we measure it; if we are to estimate its size, we must do so while it is in motion relatively to us. And similarly if you want to estimate the size of an electron, you have to do so while it is in rapid motion, because it never stands still for a moment. This is the sort of problem with which the theory of relativity is concerned. Measurement with a foot rule, when it is possible, gives always the same result, because it gives the "proper" length of a body. But when this method is not possible, we find that curious things happen, particularly if the body to be measured is moving very fast relatively to the observer. The figure opposite will help us to understand the state of affairs.

Let us suppose that the body on which we wish to measure lengths is moving relatively to ourselves, and that in one second it moves the distance *OM*. Let us draw a circle round *O* whose radius is the distance that light travels in a second. Through *M* draw *MP* perpendicular to *OM*, meeting the circle in *P*. Thus *OP* is the distance that light travels in a second. The ratio of *OP* to *OM* is the ratio of the velocity of light to the velocity of the body. The ratio of *OP* to *MP* is the ratio in which apparent lengths are altered by the motion. That is to say if the observer judges that two points in the line of motion on the moving body are at a distance from each other represented by *MP*, a person moving with the body would judge that they were at a distance represented (on the same scale) by *OP*. Distances on the moving body at right angles to the line of motion are not affected by the motion. The whole thing is reciprocal

that is to say if an observer moving with the body were to measure lengths on the previous observer's body, they would be altered in just the same proportion. When two bodies are moving relatively to each other, lengths on either appear shorter to the other than to themselves. This is the Fitzgerald contraction, which was first invented to account for the result of the Michelson-Morley experiment. But it now emerges naturally



from the fact that the two observers do not make the same judgment of simultaneity.

The way in which simultaneity comes in is this: We say that two points on a body are a foot apart when we can *simultaneously* apply one end of a foot rule to the one and the other end to the other. If, now, two people disagree about simultaneity, and the body is in motion, they will obviously get different results from their measurements. Thus the trouble about time is at the bottom of the trouble about distance.

The ratio of *OP* to *MP* is the essential thing in all these matters. Times and lengths and masses are all altered in this proportion when the body concerned is in motion relatively to the

observer. It will be seen that, if *OM* is very much smaller than *OP*, that is to say if the body is moving very much more slowly than light, *MP* and *OP* are very nearly equal, so that the alterations produced by the motion are very small. But if *OM* is nearly as large as *OP*, that is to say if the body is moving nearly as fast as light, *MP* becomes very small compared to *OP*, and the effects become very great. The apparent increase of mass in swiftly moving particles had been observed, and the right formula had been found, before Einstein invented his special theory of relativity. In fact, Lorentz had arrived at the formulae called the "Lorentz transformation," which embody the whole mathematical essence of the special theory of relativity. But it was Einstein who showed that the whole thing was what we ought to have expected, and not a set of makeshift devices to account for surprising experimental results. Nevertheless it must not be forgotten that experimental results were the original motive of the whole theory, and have remained the ground for undertaking the tremendous logical reconstruction involved in Einstein's theories.

We may now recapitulate the reasons which have made it necessary to substitute "space-time" for space and time. The old separation of space and time rested upon the belief that there was no ambiguity in saying that two events in distant places happened at the same time; consequently it was thought that we could describe the topography of the universe at a given instant in purely spatial terms. But now that simultaneity has become relative to a particular observer, this is no longer possible. What is, for one observer, a description of the state of the world at a given instant, is, for another observer, a series of events at various different times, whose relations are not merely spatial but also temporal. For the same reason, we are concerned with *events,* rather than with *bodies.* In the old theory, it was possible to consider a number of bodies all at the same instant, and since the time was the same for all of them it could be ignored. But now we cannot do that if we are to obtain an objective account of physical occurrences. We must mention the date at which a body is to be considered, and thus we arrive at an "event," that is to say something which happens at a given time. When we know the time and place of an event

in one observer's system of reckoning, we can calculate its time and place according to another observer. But we must know the time as well as the place, because we can no longer ask what is its place for the new observer at the "same" time as for the old observer. There is no such thing as the "same" time for different observers, unless they are at rest relatively to each other. We need four measurements to fix a position, and four measurements fix the position of an event in space-time, not merely of a body in space. Three measurements are not enough to fix any position. That is the essence of what is meant by the substitution of space-time for space and time.

A. C. B. LOVELL

Radio Stars

One of the most exciting events in astronomy in many years is the development of radio astronomy. It is exciting because it provides man with a new "window" into space—and just in time. In the past, man has depended on visible light and optical instruments for studying the stars. Optical telescopes, however, have gone nearly as far as they are likely to go; it is doubtful that a bigger "eye" than the 200-inch telescope at Mount Palomar will ever be built. Aside from cost, big telescopes can be used for only a comparatively few nights a year—and the bigger the fewer—because of atmospheric interference. The alternatives are to station a telescope and crew of astronomers out beyond the earth's atmosphere (a feat that will be a few years in the doing, rocket enthusiasts to the contrary) or to find a way of "looking" at stars that the earth's atmosphere does not interfere with. Radio astronomy is such a way. A. C. B. Lovell is professor of radio astronomy at the University of Manchester, England, and his article is reprinted, with permission, from the January, 1953 (Vol. 188, No. 1), issue of the *Scientific American*.

When a country that is struggling with a financial crisis and shortages of raw materials decides to spend a million dollars and 2,000 tons of steel on a single instrument for fundamental research, big dividends must be expected. Great Britain is now making such an investment in a new kind of gigantic telescope. It will be concerned with what may seem a visionary enterprise—the exploration of the universe—but Britain anticipates a rich harvest of discovery from the investment.

The story behind the decision to build this instrument is a thrilling chapter in the history of research. It is the story of radio astronomy. Until twenty years ago our only window into space was the visual region of the electromagnetic spectrum. We knew that our vision was somewhat obscured by dust and vapors clouding the starlight, but it seemed unlikely that outer space had many secrets which our great optical telescopes would not eventually reveal. Then quite by accident a new window was discovered in another part of the electromagnetic spectrum. While studying atmospheric radio disturbances Karl G. Jansky, an electrical engineer at the Bell Telephone Laboratories, picked up radio signals which he decided must be coming from outer space. His now famous discovery was confirmed by the radio engineer Grote Reber, who built in his garden a thirty-foot parabolic aerial with which he plotted the first radio map of the sky.

Reber's survey showed that the signals were strongest from the direction of the Milky Way, and that in general the regions of space with the thickest clusters of visible stars emitted the strongest radio waves. But Reber was not able to connect the radio signals with any specific object. He pointed his aerial in the direction of bright stars, extra-galactic nebulae, and other strong emitters of light, but none of them seemed to be the cause of the radio signals! Reber concluded that the radio waves probably were generated by atomic processes in the hydrogen gas in interstellar space. It was an interesting theory, but apparently not destined to lead to any startling revelations about the universe.

Astronomers at first took little account of the radio experiments. In 1948, however, there came a new development which decidedly quickened their interest. Reber's difficulty had been that his radio telescope had very poor resolution: it could not separate small objects in the sky because it received radiation in a beam several degrees wide. To focus on a small object a telescope must look into space in a narrow beam, and this requires that the reflector or other radiation receiver be very much larger than the wave length of the radiation. The wave length of the light waves collected by an optical telescope is only a few hundred thousandths of an inch. But the radio sig-

nals received by Reber's telescope had a wave length of about six feet, and his thirty-foot antenna could receive only a broad beam. In 1948 two experimenters on opposite sides of the world found a way to get better resolution of the sources of the radio signals. They were J. G. Bolton in Sydney, Australia, and Martin Ryle in Cambridge, England. They used a combination of two antennas, placed several hundred yards apart and connected to a single radio receiver. Radio waves coming in obliquely from space reached one aerial slightly before the other and therefore produced an interference effect, either reinforcing or opposing each other. As the earth rotates, this radio "interferometer" sweeps the sky with a fan of fine lobes, thus making it possible to get some idea of the size of the radio-broadcasting region in space; a source smaller than the space between the lobes would produce sharp maxima and minima in the strength of the received signal. To the great astonishment of astronomers, Bolton and Ryle found that at least some of the radio waves were coming from sources small enough to be called "radio stars." Bolton found one in the constellation of Cygnus, and Ryle discovered an even stronger one in Cassiopeia. Subsequently many more radio stars were located.

The strangest feature of these discoveries was that none of the radio stars seemed to coincide with a bright star or any other visible object. The belief soon arose that the radio stars represented a hitherto unknown type of stellar object—dark or only faintly luminous, but with the facility of emitting intense radio waves. There seem to be a great number of these radio stars: more than two hundred are now known, and it is very likely that vastly greater numbers will be found as radio telescopes are improved. In fact, there are grounds for believing that radio stars may be as numerous as the common visible stars.

In 1950 a large radio telescope was built at the Jodrell Bank station of the University of Manchester in England. It is similar in shape to the one originally used by Reber, but 220 feet in diameter, so that it can receive radio signals in a beam only two degrees wide. Its antenna is fixed, however, and it can survey only a small part of the sky. With this telescope R. Hanbury Brown succeeded in recording radio waves emanating

from the great spiral nebula in Andromeda and from more distant galaxies. Thus it became evident that radio stars must be common not only in the Milky Way but also throughout the universe.

Determined efforts have been made to unravel this strange mystery of a universe filled with radio-emitting bodies which have no obvious connection with the common stars, and in the last few months a little progress has been made. Among the radio stars detected by Bolton is one in the constellation of Taurus which coincides with an outstanding celestial object known as the Crab nebula. This nebula is believed to be the hot, expanding, gaseous shell of a supernova which exploded in 1054. The position and size of the radio star, the third most intense in the sky, coincide well with the position and size of that gaseous shell. Last summer Brown discovered a radio star in the position of another supernova—the one observed by Tycho Brahe in 1572, the remnants of which are no longer visible in telescopes. Hence it now seems well established that the remains of a great stellar explosion are capable of generating intense radio waves. One more check is needed to place the matter beyond doubt: detection of radio waves from the remains of the third known supernova, observed by Johannes Kepler in 1604. Unfortunately Kepler's object is outside the field of view of the fixed radio telescope at Jodrell Bank, and no other instrument of sufficient size is available to study it.

These three supernovae would account for three radio stars, but what about all the others? To study the situation more closely the astronomers on Palomar Mountain trained their 200-inch telescope on the region of sky containing the two most intense radio stars in Cassiopeia and Cygnus. This search, which began early in 1952, has been very fruitful. Near the Cassiopeia radio star the telescope has revealed a region of diffuse gaseous nebulosity with some strange and still unexplained properties. The result of the investigation of the Cygnus region is even more startling. The Palomar observers Walter Baade and R. Minkowski believe that the Cygnus radio star is caused by the collision of two galaxies!

The general findings so far are indeed remarkable. Of the three strongest radio stars in the sky, one seems to be the re-

mains of a star which suffered a violent death, another appears to represent whole galaxies in collision, and the strongest of all seems to be a very faint region of gas in violent motion.

As the sky has been plotted in greater and greater detail with radio telescopes of improved resolving power, it has become clear that the regions with the greatest concentrations of stars generate the most intense radio waves. Even in our present state of uncertainty regarding the source of the radio waves, this relationship is of the utmost importance to astronomy. Our view of the star-rich central regions of the Milky Way is badly obscured by clouds of minute dust particles in interstellar space. In fact, it has been estimated that this dust must hide over ninety per cent of the stars in the Milky Way from visual detection by even our most powerful telescopes. Naturally this is a severe impediment to the study of the structure of our galaxy. Radio waves, however, can penetrate the dust without absorption and bring to the radio telescopes details of the hidden regions. The radio plotting of the sky is, therefore, a most important task. The work needs high resolution and we have seen that this requires very large radio telescopes. That is the reason for undertaking the new telescope at Jodrell Bank.

Its design is based on the radio telescope which has been in use there for several years, but it will be much bigger, and instead of being fixed in one position it will be movable, so that it can be trained on any part of the sky. Some 500 tons of steel and concrete are now being sunk into the ground as the foundation for the instrument. The foundation will support a superstructure of 1,500 tons, mounted on a circular railway and driven by motors which will enable it to track automatically any object in the heavens. Its great antenna will be a steel bowl 250 feet in diameter and 60 feet deep at the center; the 300-ton aerial will pivot on an axis 180 feet above ground level.

The primary assignment of this great telescope will be to survey the heavens, but it will also be equipped for all other types of work in radio astronomy, including radar tracking of meteors.

The telescope will operate over a wide range of radio wavelengths. Until recently most of the work in radio astronomy

was done in the range of wave lengths between one and twenty meters. But there has been increasing interest in the use of shorter wave lengths, and in 1951 this field was given a tremendous stimulus by one of those spectacular discoveries that have been so characteristic of work in radio astronomy. It had been suggested that the hydrogen atoms in interstellar space might, as the result of a certain change in energy state, emit radio energy at a wave length of 21 centimeters. In 1951 radiation of this wave length was actually detected, first by Harold I. Ewen and E. M. Purcell at Harvard University and then by others. Thus for the first time astronomers had a specific spectral line to work with in the radio spectrum. The lines in the visible spectra of the stars have been, as everyone knows, of enormous value to astronomy; for one thing, they have been the basis of the studies of the red shift in the light from distant stars and led to the theory of the expanding universe. In the same way studies of slight Doppler-effect shifts in the 21-centimeter radio line will make it possible to determine the relative motion of the earth and the clouds of hydrogen gas in space.

Astronomy has marched forward with the growth in size of its telescopes. The need is always for more light-gathering power and more resolving power. In radio astronomy history will doubtless repeat itself; the building of radio telescopes with more sensitivity and more resolving power should yield striking advances in our knowledge of the universe. High hopes are entertained for the great engineering enterprise now under construction at Jodrell Bank. In combination with visual observations through the giant optical telescopes on the California mountains, it may well open a new era for astronomy.

DONALD H. MENZEL

A Panoramic Sunscape

A panoramic look at the sun is provided in this chapter from *Our Sun* by Donald H. Menzel (reprinted by permission of Harvard University Press; illustration reprinted by permission of the High Altitude Observatory, Climax, Colorado). Dr. Menzel is director of the Harvard College Observatory and one of the world's foremost authorities on the sun.

Have you ever seen the sun? Really seen it, in all of its intri cate detail? For, of course, we are all aware that somewher in the sky is a brilliant source of light, which hurts our eyes i we accidentally look at it directly. But probably you have neve really seen it. When the heavens are partially overcast or whe the sun is close to the horizon, we see the sun's circular disk but little else of detail. Occasionally, a sunspot group, whe extra large, may be visible to the naked eye. The ancient Chi nese annals contain many references to spotted areas of th solar disk. Groups of this magnitude are fairly uncommon however, and ordinary spots can be detected only with tele scopic aid.

How to Observe the Sun

Observation should not be undertaken without some protec tion for the eyes. Very dark glasses, a piece of heavily smoke glass, and fogged photographic films are used most commonl Two "polaroid" filters, superimposed, are ideal, because rota tion of one member with respect to the other allows the observ to select exactly the desired intensity of transmitted light.

Any filter tends to change the color of solar radiation. For that reason the student may wish to adopt the simple and effective method of punching a very fine pinhole in a visiting card. Then, holding the card close to his eye, he may examine the sun, cautiously at first, and consequently view it in its true color. The experiment is well worth performing, for it gives one a very clear idea of the sun's apparent diameter, which is much smaller than the average person would estimate from casual observation. In addition, it emphasizes the silvery color of sunlight. Most persons who have seen the solar disk when the sun is near the horizon and, therefore, reddened by absorption of the long path of intervening air, have the idea that the sun is orange or perhaps golden. Actually, sunlight is white, or very nearly so.

The pinhole is also useful as a projector, especially when the sun's image is formed by it within a darkened room. A one-inch image of the sun will appear on a piece of white paper held ten feet away from the pinhole. Large spot groups should be clearly visible. But, if any simple optical aid, like a telescope, field glasses, or even modest opera glasses, is available do not bother with the relatively ineffective pinhole. With dark glass placed before the lens, one may easily view the sun directly and see its surface characteristics. Take great care with the dark glass and never look at the sun directly without such protection.

Astronomers frequently employ an alternative method of observation. Focus one of the above instruments upon a white screen held a foot or two behind the eyepiece. The enlarged solar image, thus projected, can be examined directly. A second screen, with an aperture to admit the front of the telescope, should be used to cast a shadow upon the image. . . .

However the sun is observed, whether with the naked eye or a powerful telescope, there is one feature that should be entirely obvious: the solar disk is by no means uniformly bright all over. The intensity is greatest at the center and diminishes toward the edges. This phenomenon, known technically as "limb darkening," arises because the solar surface, instead of being sharply bounded, is surmounted by a layer of atmosphere.

Sunspots

The widely publicized phenomenon of sunspots is the most obvious variable feature of the sun. When Galileo turned his telescope sunward he was undoubtedly surprised to find dark areas here and there against the shining solar surface. A few weeks of observation sufficed to show that these spots were truly part of the sun and not planets or other solid bodies seen in projection. Galileo found the sun to be rotating, and that a few days less than a month were required for a complete turn on its axis. Recognizing the far-reaching significance of his observation, which was so at variance with the philosophies of his time, Galileo did not immediately publish his results. Meanwhile others, among them Fabricius and Scheiner, discovered the phenomenon independently. The latter argued that the spots could not be truly on the sun.

At last Galileo spoke, simply and effectively. "Repeated observations have finally convinced me that these spots are substances on the surface of the solar body where they are continuously produced and where they are also dissolved, some in shorter and others in longer periods. And by the rotation of the sun, which completes its period in about a lunar month, they are carried round the sun; an important occurrence in itself and still more so for its significance."

The individual spots proved to be temporary phenomena. The smaller ones are very short-lived, lasting but a day or so. The larger ones, with fully developed penumbrae, may persist for several weeks. Relatively few remain visible long enough for solar rotation to bring them into view a second time. Several spots have lasted ninety to a hundred days. Reports of longer durations are attributable to persistence of an active region.

High telescopic magnification reveals the detailed structure of a sunspot: the dark central core, known as the *umbra*, rimmed by the delicate filaments of a less-dark region, the *penumbra*. Sunspots are never exactly round. The edge of the umbra is usually jagged, with the outline of the penumbra roughly parallel to it. In places, the filaments of the penumbra project well beyond the general outline of the spot, like little patches of hay spilled around the edges of a haystack.

Occasionally, spots occur singly. More often they are found in pairs, or in complex patches. A representative group ordinarily contains two spots of major dimensions, with perhaps several dozen smaller spots irregularly distributed in the neighborhood. A sunspot is usually the scene of great activity. At times, one is traversed by a brilliant bridge that cuts the spot in two. The entire character of the phenomenon may change markedly in the course of a few minutes. Then, after days or weeks, the spot may disappear, leaving bright veins as the last trace of the disturbance. The pattern of bright patches associated with spots, we call *faculae.*

The discovery of sunspots presented a problem as to their nature. I have already pointed out that most primitive races had regarded the sun as a god. This deification was supported by Aristotle, who pronounced the view that the sun was a ball of *pure fire*. I italicize both words because the emphasis was fully as much on the first word as on the second. Consequently, a large number of people regarded the finding of spots as impeaching the pure character of the sun, because spots and purity could not be reconciled. Many persons refused to look through the telescope, lest they, too, become bewitched and see the defilement that did not accord with the teachings of Aristotle, prince of philosophers. The invention of the telescope and the discoveries made with its aid went far toward undermining the unreasoned devotion to Aristotle's authority. . . .

For sunspots proved to be real phenomena. Galileo regarded them as clouds floating in the solar atmosphere, and, in this view, he was less far from the truth than many who followed him. Others argued that the spots were mountains projecting above the luminous clouds. Many thought them to be produced by some sort of volcanism. . . . Our view today [is] that sunspots are storms, perhaps of cyclonic character.

As in the terrestrial atmosphere, there are regions of low pressure toward which the gases in high-pressure areas tend to flow. The resulting expansion of the gases cools them. On earth the moisture-laden air, thus cooled, can hold less of its water vapor. Condensation and precipitation result. On the sun, the gases are far too hot for condensation. Even the heavy metals occur in vaporous form. But the cooler areas manifest

themselves visibly by radiating less energy than the surrounding regions. Thus the storm centers appear dark by contrast.

We find spots in all varieties of sizes. The smallest ones, which are usually called *pores,* a few hundred miles or so across, are the most numerous. Very likely even smaller disturbances than these occur, but they are too tiny to be seen through a telescope. At the other end of the scale, we often find spots whose diameters, including the penumbra, may measure 20,000 miles or more. A large double group may extend 100,000 miles or more, with a disturbed area of several thousand million square miles. The largest spot on record, which apeared in April 1947, covered more than one per cent of the area of the apparent solar disk. Its total area was about 6,000 million square miles. The spot could have contained about a hundred earths. Any spot larger than 25,000 miles in diameter is readily discernible to the naked eye.

Solar Variability

As one follows the appearance of the sun from day to day and year to year, keeping records of the numbers and areas of spot groups, he will find a gradual and fairly regular rise and fall of solar spottedness. Schwabe, of Dessau, in 1851, was the first to recognize the existence of periodicity in sunspots from twenty-five years of his own careful observations. Later, R. Wolf, of Zurich, found an unpublished manuscript dated 1776 written by the Danish scientist Horrebow, which suggested the possibility of a periodic variation in the sunspots. Wolf succeeded in uncovering many such observations of the earlier astronomers and thus was able to extend our knowledge of sunspot numbers back to the invention of the telescope in 1610, with a practically unbroken record from 1745.

The average spacing between successive maxima is 11.? years, but the relation is by no means exact. A maximum occurred in 1788 and the next was not reached until sixteen years later, in 1804. And then again the maximum in late 1829 was quickly followed by one in early 1837, an interval of about 7.5 years. . . .

Granulation and Faculae

Sunspots are only one indication of the storminess of the solar atmosphere. They were discovered first because of the sharp contrast that makes them conspicuous, even in a small imperfect telescope. Much higher powered and better instruments are required to disclose the structure of the shining surface between the spots. This area is seen to be far from uniform and presents a granular appearance often referred to as "rice grains." The appellation must be attributed to the astronomer who asserted that the granulations look like "rice grains floating in a bowl of soup." The simile is suggestive, even though it displays the scientist's ignorance of the indisputable culinary fact that rice grains sink to the bottom of the bowl.

The solar rice grains, tiny brilliant patches several hundred miles or so across, standing out against the darker background, appear mostly near the center of the disk. Photographs show that the individual grains are indeed short-lived. Within the course of several minutes the entire character of the pattern may change completely. The rapidity of the variations is indicative of the turbulent state of the sun's atmosphere. On the earth we refer to a 90-mile-an-hour wind as a hurricane or tornado. On the sun, atmospheric motion of that speed would be counted as mere stagnation, for velocities upward of ninety miles a second are not uncommon.

Associated with the spotted areas occur great patches of bright material called *faculae* ("little torches"). These form a veined network that is much larger than the dark spots. Also they seem to be more permanent. Presumably they are elevations of a sort, temporary mountains of gas in a gaseous atmosphere. They are most conspicuous near the limb, i.e., the edge of the solar disk.

Prominences

The turbulence of the sun's atmosphere is shown most graphically, perhaps, by the great eruptions of gas that occasionally burst from the solar limb. These eruptions, which are called

"prominences" or protuberances, have the appearance of enormous flames. They are indeed great clouds of luminous gas, but they are not true flames in the ordinary sense, because they do not owe their luminosity to combustion. The sun is not "on fire." Prominences are ordinarily visible only with very special equipment. . . . But at the time of total solar eclipse, when the moon blots out the brilliant disk of the sun, prominences appear as elevated rosy patches of cloud sometimes floating high above the solar surface.

The motions and forms of prominences are subjects for special investigation. Some of the clouds are of truly eruptive character, being shot upward with explosive violence. Others remain suspended like fleecy summer clouds, showing evidence of internal motion, and all but detached from the solar surface. Some form swiftly at high levels, with no obvious source, and rain luminous streams sunward in graceful curves. Still others, usually associated with sunspots, shoot out like a ribbon of flame and then are drawn back, as if a sunspot had extended a snakelike tongue and then withdrawn it. Prominence and sunspot activity are clearly related; the physical nature of both is understood to some extent, but the causes underlying their existence and variations are not known.

Corona

Prominences, particularly the high eruptive ones, move through a region of space that is far from being a perfect vacuum. The sun is completely enveloped in an aura of tenuous atmosphere. The atoms of this outer solar fringe, which is known as the corona, emit a feeble radiation that is ordinarily entirely concealed by the bright glare of the sun and surrounding sky light. Only when the sun is completely eclipsed by the moon can the corona be readily seen. Then we perceive it as a delicate system of rays, with a definite structural pattern of filamentary streamers.

The coronal streamers extend millions of miles out into space. There is evidence that, on occasion, they may even brush the earth, producing magnetic storms and brilliant auroral displays in transit. The corona, like sunspots and prominences, also de

Three stages of development of an eruptive arch formed from clouds of luminous gas on the surface of the sun.

pends for its form and structure upon the condition of sol activity. At sunspot maximum, the corona presents a wind blown aspect with streamers stretching irregularly in every di rection. At sunspot minimum, the corona appears to have bee carefully combed with a neat part at the poles and long hair streamers stretching out from the equatorial regions.

Solar Rotation

The rotation of the sun, already mentioned, presents an inte esting puzzle. The rotation is not like that of a solid body. Th sun's equatorial regions make the circuit in less time than th intermediate latitudes, a conclusion drawn from the fact th spots near the equator move ahead of those nearer the pole The reason for this "equatorial acceleration" is unknown. Th planets Jupiter and Saturn show a somewhat similar behavio

Determination of the direction of the axis of rotation is simple matter. If the axis were perpendicular to the plane the earth's orbit, spots would always seem to move in straigh line paths across the disk. Actually, this sort of motion is o served only about June 6 or December 6. At other times spo travel in curved paths, the maximum of curvature being reache at the intermediate dates of March 8 and September 8. . . . Th curvature is not great but, when carefully measured, it fix the inclination of the sun's axis at about seven degrees to th perpendicular of the earth's orbit plane. From June to Decem ber, we view the sun's north pole and, during the other half o the year, the south pole.

A point on the sun's equator completes a rotation in twent five days. Its speed is some 4,500 miles an hour, about fo times the velocity of a similar point on the earth's equator. No the earth departs markedly from a spherical form as a resu of its rotation. Its polar diameter is twenty-seven miles le than the equatorial, because of the centrifugal force develope The question is: can we observe a similar flattening to the pol for the sun?

The problem is not an easy one to answer, because the sun departure from sphericity is so small as to defy measureme True, observers have found differences on the order of

hundredth of one per cent, about one hundred miles. But the measures are as likely as not to indicate a polar diameter greater than the equatorial, which we are indeed loath to believe. The difficulty lies in the observations themselves. Light from the lower edge of the sun's disk has to traverse a slightly greater thickness of the earth's atmosphere than does light from the upper edge. This difference of path, minute though it may be, nevertheless introduces errors, with uncertain corrections. We feel sure that some flattening must exist, but we shall have to devise new methods of observation before we can determine its magnitude.

Measurement of the equatorial diameter is much simpler than of the polar. The east and west edges of the sun have, at noon, the same altitude above the horizon. Consequently, the light paths through the atmosphere are essentially identical, and the corrections are automatically eliminated. We do not have to point our telescope first to one edge and then to the opposite edge of the sun and measure the angle we have turned the instrument through. Instead, we direct the telescope toward the meridian and wait for the sun to cross its field of view. We punch a telegraph key at the moment the preceding limb touches the crosswire and punch the key some two minutes later as the following limb drifts past the index mark. The telescope, meanwhile, is stationary; hence we easily calculate the diameter from the recorded time elapsed between the two contacts.

It is much easier to measure time than angles. To achieve an accuracy of a hundredth of one per cent, we have only to record the duration of the transit to about one one-hundredth of a second. Since short time intervals may be fixed with still greater precision, if necessary, this part of the study presents no serious difficulty. The earth's atmosphere makes all of the trouble. For unless the air is exceptionally clear and steady, the edge of the sun is wavy and indefinite, not sharp and well marked, as the study requires. Even when the atmosphere is not moving, any trace of haze serves to make the sun appear larger than it really is. This effect, known as "irradiation," may amount to as much as a tenth of one per cent.

Long series of observations seem to indicate, in spite of

the numerous difficulties, actual variation in the equatorial sol diameter. In view of the enormous forces of solar activity, small change in the surface layers is not in the least disquietin Secchi and Rosa concluded that the sun is larger during su spot *minimum*. One might have expected just the reverse: larger sun when the atmosphere was most disturbed by spo and prominences. The result needs checking by the best modern methods. In passing, we may note that many sta themselves variables in light, show pulsations in diameter ten per cent or more.

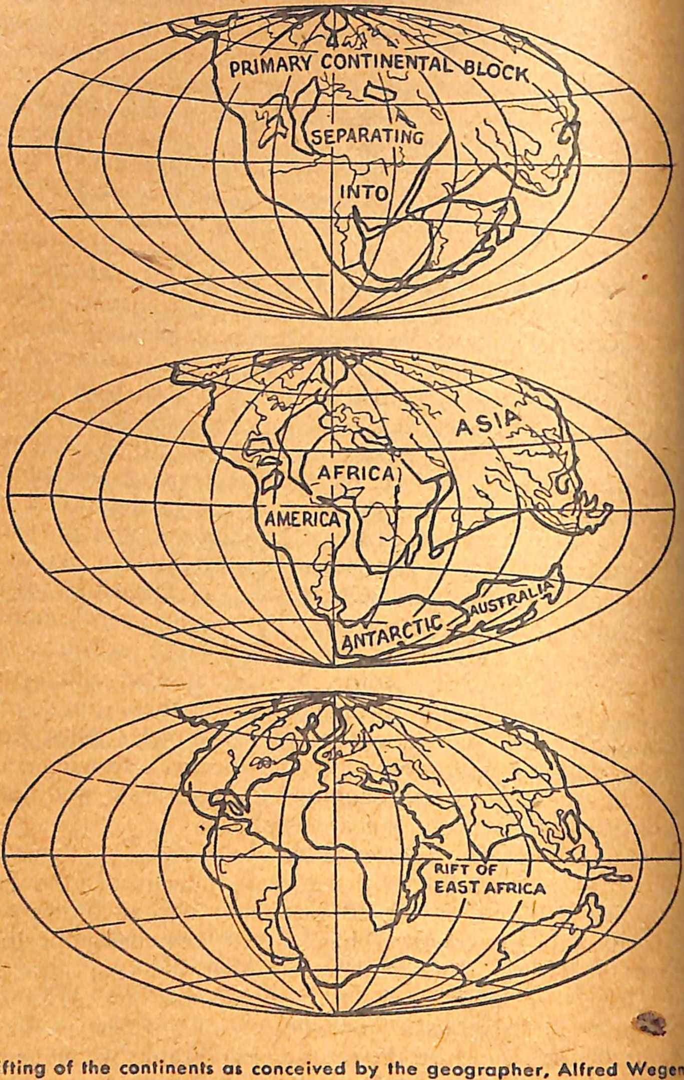
FRITZ KAHN

The Theory of the Floating Continents

One of the great achievements of science has been the demonstration that the earth has a history. The continents, the mountains and valleys, the plains and shores we know were not always here. In the past—the geological past, that is—the earth had a different face; in the future, it will have another face again. Three main factors have been recognized as playing a part in the shaping of the earth's crust. They are folding of the crust, the rise and fall of seas, and weathering. A fourth possibility is drifting of the continental land masses in the sea of magma, the plastic, semi-molten layer beneath the earth's outermost mantle of rock. This intriguing possibility is presented by Dr. Fritz Kahn in the chapter reprinted below (by permission of Crown Publishers, Inc.) from Part Four, "The Heavens and the Earth," of Dr. Kahn's latest book, *The Design of the Universe*. The illustrations are redrawn from the same volume. Dr. Kahn is a professional scientist who in recent years has devoted ever more of his time to the explanation and popularization of science.

The Birth of a Theory

In 1823 the English geographer Edward Sabine discovered a small island off the eastern coast of Greenland and determined its geographical location. In 1869 geographers rechecked the location and ascertained that the island was 420 meters farther west than the point given by Sabine. The difference exceeded the usual margin of error, but the geographers did not argue about it.



Drifting of the continents as conceived by the geographer, Alfred Wegen

Forty years later another group of geographers, in the course of one of the periodic expeditions sponsored by the Danish government, checked the coast of Greenland again. A young participant, Alfred Wegener, found at this time that Sabine Island was about one kilometer to the west of the position given in 1869. He came to the conclusion that the island, not the measurements of the geographers, must be "wrong"; it must have changed its geographical position. On checking the positions of other arctic land masses, he found that they all drifted westward at varying speeds, and promoted the theory that Greenland is shifting about twelve feet to the west every year. America, too, is moving westward; the distance between Cherbourg and New York increases about one millimeter, one-twenty-fifth of an inch, every day. The American soldiers who crossed the Atlantic in World War II had to travel thirty feet farther than did their fathers in World War I.

All places on the surface of the globe change their geographical position. The architects of ancient Egypt would gape in amazement if they saw the Pyramid of Cheops today. It is now about two and a half miles south of where they erected it. If Ulysses were to revisit the scenes of the Odyssey, he would look in vain for Scylla and Charybdis. The Strait of Messina, whose width in ancient times was one and three-tenth miles, is now almost two miles across, and the whirlpool that once made the Narrows of Messina notorious has subsided into a mere current. The Strait of Gibraltar is about three times wider today than when it was known as the Pillars of Hercules. Rome is shifting toward the equator, North America is moving southwestward, Australia is approaching the South Pole, and the insular world of Polynesia is scattering.

There is a distinct difference between fact and theory. It is a fact that frogs spend the first part of their lives in the water as tadpoles. That they do so because their ancestors were aquatic animals is a theory. That land masses change positions seems to be a fact. The explanation that Wegener gave is a theory, the "theory of the drifting continents," and one which is still a subject of discussion among geologists. Despite the debatability of the theory, in the ensuing paragraphs we will speak as if the assumptions were facts, just as an astronomer might

present the theory of the "expanding universe" or the geneticis the theory of the genes. It would be tiresome to begin ever paragraph with the statement that the topic presented therei is hypothetical.

The idea of the drifting continents had been expressed sever times before; in the seventeenth century by Francis Bacon; i the eighteenth by the French father of modern zoölogy, Georg Louis Buffon; and in the nineteenth by the American astro omer, Edward Charles Pickering. Yet Wegener is justly call its creator, since in science the father of a theory is not the m who casually voices it but he who first recognizes the signi cance of an idea, devotes time and talent to a thorough inves gation, correctly formulates his theory and is forced to ov come the resistance of the contemporary "guardians of t acknowledged truth"—and in so doing receives for "his" theo the proper place in history. Thus the Roman naturalist L cretius Carus and the German amateur scientists Goethe an Herder are considered only the precursors of the theory of ev lution; Lamarck and Darwin are properly honored as its foun ers and the fathers of evolutionist thinking. Columbus is r vered as the discoverer of America, even though seafarers many nations reached the coast of the continent several tim before his expedition. James Watt is called the inventor of t steam engine and Einstein the creator of the theory of re tivity, although both had "precursors."

Unfortunately, Wegener perished on a one-man skiing e pedition into the immense vastness of Greenland. Starvi amidst the frozen desert wastes, he erected a catafalque f himself out of snow, posted his skis as columns and died li a brave soldier at a forlorn outpost. His death affected t whole course of modern geology. Since then no successor equal ingenuity and enthusiasm for the theory of the floati continents has emerged.

The Dismembered Continents

When the versatile Francis Bacon studied the first cru maps of America, he was immediately struck by the exactn with which the eastern coastline of the Americas fitted into t

western coastline of Europe and Africa and expressed the idea that Europe, Africa, and the Americas are fragments of a great primordial land mass. Wegener called it Pan-Gaea, the "Whole-World" of the early ages.

The portrait of Pan-Gaea that Wegener drew about 1910 is now outmoded and his explanation of continental drift based upon twist and polar motion is now considered oversimplified. Yet his ingeniously conceived pictures illustrates the theory with unsurpassable clarity.

Not only do the outlines dovetail with one another but the mountain ranges of far-flung continents and islands match like the pieces of a broken dish. Even the sunken geological strata fit together, like the painted flowers on the fragments of the broken pieces of porcelain.

In the Northern Hemisphere a chain of mountains—the protruding scar of a trench that had once been open but now is healed—begins in Europe, runs across Scandinavia and continues westward through England and beyond the Atlantic into North America. In the Southern Hemisphere a long trench—actually not one trench but a chain of related trenches—runs through the South American continent, crosses the southern tip of Africa and continues to the coast of Australia. It is named the South-American-African-Australian Graben, shortened to "Samfrau." Originally the graben was not so long as it is now. Today the trench and its mountain chain are spread out across half of the globe. The homogeneity of this long chain of trenches manifests itself in many ways. Strata, ores, minerals and other deposits follow the grooves of the trenches. The most conspicuous of the many sporadic deposits is gold. On the American side there is the gold of Peru that played so sinister a role in the conquest of "El Dorado" by the Spaniards ending with the virtual extinction of the pre-Columbian peoples. Two hundred and fifty years later the gold of South Africa motivated the British attack on the peaceful Boers. Tens of thousands of fortune seekers lured by fabulous deposits of gold migrated to the southeastern end of the Samfrau Graben where the vast deserts of the Australian hinterland became the setting for innumerable tragedies.

The opponents of the theory point out that the contours of

the continents, islands, and strata do not always fit correct Yet the crust of the earth is not made of brittle porcelain b of semiplastic rock-dough. When continents have separate their rims may retreat or, contrarily, may creep outward. T continent of North America lost about one hundred miles breadth as a result of the upward fold of the Appalachians, a the southern tip of Africa is being shortened at present by t rise of mountains north of the Cape. Finally, continental fr ments rotate while drifting, much as lumps of ice do wh they float in a river.

As the continents broke off, their plants and animals w separated. The forests of the carboniferous era, which are ploited today as coal beds and are revealingly scattered in girdle extending from Pennsylvania eastward, then from Fra through Belgium, Silesia, Poland to the Don and the Don basin, probably once formed a single broad belt of green. T distribution of several species of spiders, crabs and scorpio molluscs and earthworms, and also early mammals supports t theory. Seacows are an often cited example. Fresh-water ma mals, they live mainly in the estuaries of great rivers and neighboring coasts. Of the several small groups that still s vive, one is found at the estuary of the Amazon River in Sou America and another opposite it in Africa, at the mouth the Congo. Could this be mere coincidence? Proponents the theory also point to monkeys found both in Africa and South America.

There are, of course, other possible explanations for t present distribution of animals and plants, such as the clas geological doctrine that the continents remained firm but th the seas changed their levels and extensions, and that la bridges temporarily connected the now separate continen but such theories depend on just as many assumptions, leavi so many questions open that a modern, dynamic approach see justified even if it too leaves many problems unsolved.

The Battle between Laurasia and Gondwana

The theory of continental drift shared the fate of ma scientific theories. The idea was fascinating, but it was far l

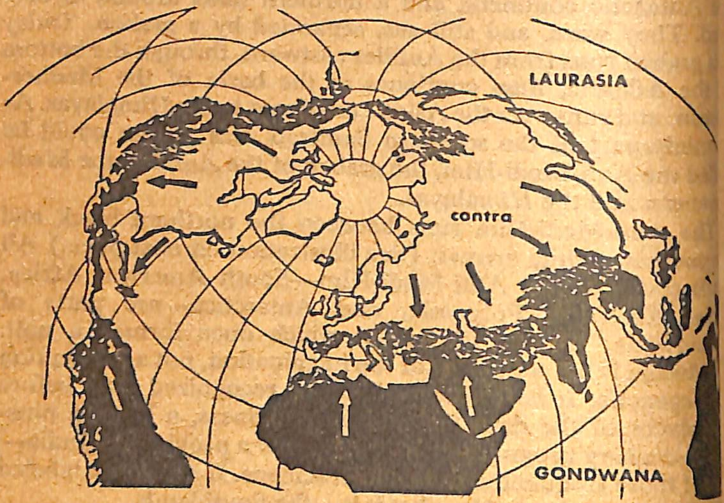
easy to insert the facts into the framework of the theory than the first "continental drifters" expected. The idea of a primordial Pan-Gaea, one great unit, proved untenable. Geological facts point to the assumption that the early land masses were gathered into two groups—a southern mass centered around the Antarctic continent, and a northern mass around Greenland. They were, and still are, separated by a graben. Today this graben runs from the Antilles eastward, through the bottom of the Atlantic, then continues as the basin of the Mediterranean, and runs over the Asiatic continent to the Himalayas. As a counterpart of the southern Samfrau, this graben could be called the Anti-Medi-Him, the graben of the *Anti*lles, the *Medi*terranean and the *Him*alayas.

The Anti-Medi-Him runs between the northern black and the southern white arrows. (See illustration on next page.) All lands south of the Anti-Medi-Him—South America, Africa, India, Australia, Polynesia, and Antarctica—are parts of "Gondwana," a vast land mass which once formed a unit. Gondwana is not a figment of the imagination, not a conception of Wegener's. It is a historical reality recognized long before the advent of the drift theory. Eduard Suess, a leading nineteenth-century geographer, named it after a province in India—one of those frequent misnomers in science. It should be labeled simply and unmistakably what it is—the Southlands.

The opposing lands north of the Anti-Medi-Him—North America, Greenland, Europe, and North Asia (Eurasia)—are grouped together as Laurasia. "Laur" is an abbreviation of Laurentian, referring to the region of Canada near the St. Lawrence River, considered the oldest part, the geological "heartland," of the North American continent. Much better than Laurasia would be the simple name, the Northlands.

These two land masses, Laurasia and Gondwana, move independently, each one tending toward the equator—pulled, for the most part, by centrifugal force—where they collide and then rebound. During the past 500,000,000 years the two land masses seem to have struck five times. For the first 250,000,000 years Gondwana was the more active; since the carboniferous period, Laurasia has taken the initiative. The Anti-Medi-Him graben between them widens or narrows, depending upon the

phase of the "battle." In periods of separation it becomes wid and is filled with water. It is then truly a "mediterranean"- the middle space between lands. Geologists refer to the Med terranean Sea as Tethys, the Grecian goddess of the sea an mother of Achilles.



According to the theory of the drifting continents, the earth's earthquake-and-volcano belt—the Antilles, the Mediterranean, Turkey, Northern Indi Indonesia, Japan—marks the "battle line" between the northern land ma (Laurasia) and southern land masses (Gondwana).

At present the two masses are said to be approaching ea other. Inevitably, the crust of the earth cracks all along th restive trench, lava erupts and volcanoes flare up. Anti-Me Him volcanoes are Popocatepetl on the American side; Etn Stromboli and Vesuvius in Southern Europe. Farther to th east are the volcanoes of Hauran, to which the Psalmist r ferred when he said: "He toucheth the hills, and they smoke

North and South America are not, as one might thin two halves of an originally uniform continent. North Ameri belongs to Laurasia; South America, to Gondwana. They a

as different as their counterparts in the Old World—Europe and Africa. At times they approach each other, crushing Central America between them. When they disengage, the Central American land masses are dismembered and the fragments lost in the sea of magma.

Today the pivotal point of the battle between Laurasia and Gondwana is the eastern end of the Mediterranean Sea, where the three continents of the Old World—Africa, Asia and Europe—meet. Here, under the impact of Africa's thrust, the earth trembles, so to say, incessantly as far back as man has recorded history. Here Sodom vanished and, when Jupiter on the heights of the Trojanic mountain Ida shook his head, said Homer, the floor beneath the feet of men trembled. Here are the islands on which the Greek philosophers lived, scattered over the Ionian Sea and there lay Pompeii under the ashes of Vesuvius for eighteen hundred years. The fury of the battle is undiminished. On the eastern front, in 1883, the island of Krakatoa exploded like a dynamite cache; on the western front, Mount Pelée, thought to be extinct, erupted and scorched the flourishing town of Saint-Pierre on Martinique on a sunny festival morning while the people filled the churches. All perished but one—a criminal who was chained in a cave and was protected from the all-parching heat wave. It was the opposite of Sodom: not the one righteous man but the one wicked man was saved.

In the diary of geology a millennium is not more than a second in man's life, and we, living only a fraction of a geologic second, might be considered travelers in a crash between the Gondwana Express and the Laurasian Limited while the cars are telescoping into one another. Abraham, we may say, who traveled in the first car, witnessed the destruction of Sodom; he himself was rescued. Pliny, spectator of the erupting Vesuvius, traveling in the next car, suffocated under the ashes near Pompeii. Goethe experienced the destruction of Lisbon in 1755; Axel Munthe, the earthquake of Messina in 1903. In the Antilles the two cars "Jamaica" and "Cuba" are turning over. Jamaica is being pushed up and slipping southward; Cuba is shifting northward; between them opens a vast chasm plunging to a depth of 20,000 feet.

Like the Antilles, the islands of the Ionian Sea betwee Europe and Asia should be doomed. The theory of the driftin continents assumes that a once solid block of land is slowl being stretched out and that the Aegean islands are the peak of drowning mountains, still hardly above water like the stack of a sinking ship. Man speaks of them as peaceful and para disical; actually, they are death-houses, and the day of execu tion is not far off—on the calendar of geology.

Current Continental Movements

Both the Laurasia and Gondwana land masses are now breal ing up. Gondwana was the first to crack and its fragments- Africa and India, Australia, Polynesia, and Antarctica—hav drifted far. But their "diaspora" is not yet at an end. Indi moving eastward, is wedging itself into the Asiatic mainlan As it advances it plows up the land mass before it, piling u high mountains. India may be much larger than the map show. Its northeastern part has thrust its way under Afghan istan and Tibet, lifting them up so that Tibet rose to becom the highest country of Laurasia and the highlands of India ar the scene of violent earthquakes. Africa is disintegrating alon its edges. Several coastal areas have already been detached an others are at the point of breaking off. Spain, geologically piece of Africa and hence a Gondwanian province, has attache itself to Europe and has become a part of Laurasia. The sear where it is joined is typically wrinkled and elevated, formin the Pyrenees. Thus the Pyrenees, not the Strait of Gibraltar represent the geological boundary between Africa and Europe On the east side, the peninsula of Arabia has also become par of Laurasia. A third fragment is the island of Madagascar which floated away from the mainland during the early Tertiar period. Parallel to the disintegrating east coast runs the Eas African Rift.

As a fortune-teller reads a man's future in the lines of hi palms, so the fate of Africa is told in its rifts. Like Madagascar Somaliland will float eastward as an island and Nyassa will fo low it. After that, the province of the Cape of Good Hop where the rise of mountains foretells the critical stress, wi

The islands off the coast of Asia, according to the theory of drifting continents, are backwash fragments broken off as the continent of Asia swings around to the north and west.

break off. The Desert of Kalahari will float after it, no long a desert but an oceanic island, flourishing like Zanzibar.

While the "bow" of a traveling continent is piled up in mountains, some magma clings to the "stern," tearing aw pieces of land. Hence, islands are drifting in the wake of t floating continents and on most of them volcanoes are acti More than seventy-five per cent of the presently active v canoes stand on these backwash islands in the sea of magm Asia offers the most spectacular example.

Asia is turning to the northwest, its backwash being alo the southern and eastern shores. The chains of islands th girdle the continent from the Aleutians in the north, ov the Kuriles, Japan, the Philippines, to the scattered world the Southern Pacific, all of them volcanic and all of th fragile, are the foam on the waves in the wake of the traveli ship.

All modern science has become dynamic. The time-honor concept of a monumental, enduring universe has exploded in the fireworks of drifting galaxies; the "forever unbreakab atom has been split into the lightning of mesons and neutrin matter, the "eternal matter," has radiated away in wav The theory of the floating continents is a timely attempt to tack geological problems with a dynamic, one could almost s a biological, approach. This is a merit the work of Wegen will never lose. The theory may be discarded; its animati influence can never be lost.

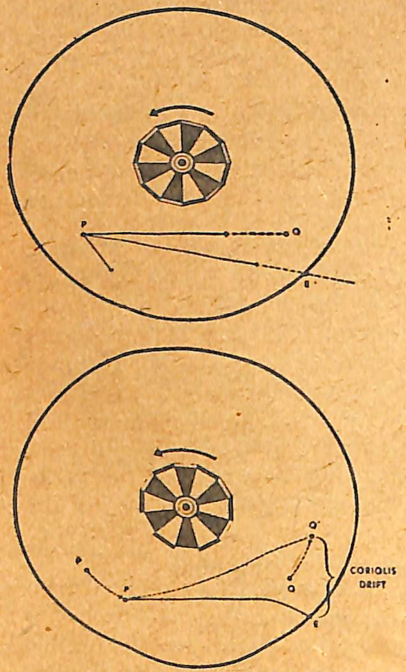
JAMES E. McDONALD

The Coriolis Effect

All of us are aware of at least one consequence of the daily rotation of the earth on its axis: the rising and setting of the sun, and the endless succession of day and night. There are other effects, however, of which few persons are aware. One of these is the curious "Coriolis effect," described in this article from the *Scientific American*, issue of May, 1952, Vol. 186, No. 5, (and reprinted by permission of the magazine). Dr. James E. McDonald, the author, is associate director of the Institute of Atmospheric Physics at the University of Arizona. The illustration is reprinted by permission of Irving Geis.

It is a curious fact that all things which move over the surface of the earth tend to sidle from their appointed paths—to the right in the Northern Hemisphere, to the left in the Southern Hemisphere. Since man has managed to make himself one of the most mobile of creatures, one might think that so ubiquitous an effect must long have been a matter of common knowledge. It has not been and still is not, even in this era of rapid speeds, which accentuate the sidling tendency. Probably few people realize that as they drive down a straight highway at sixty miles per hour this all-pervading drift would carry them off the road to the right at the rate of some fifteen feet per mile were it not for the frictional resistance of the tires to any lateral motion.

The sidewise drifting tendency is called the Coriolis effect, after the nineteenth-century French mathematician G. G. Coriolis, who made the first complete analysis of it. The effect is due simply to the rotation of the earth, and it appears in all motions as soon as we refer those motions to any co-ordinate system fixed with respect to the earth (e.g., the latitude-longitude grid).



Merry-go-round experiment demonstrates Coriolis drift. Seen from above, the merry-go-round rotates counterclockwise. In the top drawing a man at P attempts to throw a ball to a man at Q. The rotational motion of the man at P (short arrow), however, causes the ball to head in the direction PE. In the bottom drawing the man at P has moved to P', the man at Q to Q' and the ball crosses the edge of the merry-go-round at E. To the rotating observers on the merry-go-round the ball appears to have described a curve.

There is really only o satisfactory way to obtain vivid impression of the n ture of the Coriolis princip That is to go to a carniv Every carnival worth t name has a Coriolian c ordinate system: viz., t merry-go-round. With o a few balls as laborato equipment and two assis ants, one on the merry-g round with you and the oth on the ground, you can car out many interesting Cori lian experiments.

When the merry-go-rou starts up, you begin a gan of catch. Things will prob ably go very poorly for se eral throws (which is t reason for your taking t precaution of equippi yourself with several balls The ball will seem to ve from its thrown direction the most amazing fashio Let us say the merry-g round turns countercloc wise, as does the earth wh viewed from above the Nor Pole. If it makes one com plete turn in ten seconds, an you throw the ball at a spe of twenty feet per second t ward an assistant standi fifteen feet from you on t merry-go-round, the app ently curving ball will m

the assistant by a little over six feet to the right. When you throw a ball to your other assistant, in the outer world off the merry-go-round, it will again seem to drift rightward. This time, however, by great concentration you may be able to fix your attention on the nonrotating framework of the outer world sufficiently to sense that the ball is really moving as it ought to move, and you may even make proper allowance for the merry-go-round's rotation so that the ball reaches your assistant's hands.

The apparent strangeness of the balls' behavior in these experiments arises from the fact that almost inescapably you take the merry-go-round as your reference system, and in this system the laws of dynamics in their usual form simply do not hold. No such difficulties confront the assistant who stands out on firm ground. He is not so compelled to view these motions with respect to your rotating co-ordinate system. He will feel certain that the balls have at all times been moving in well-behaved fashion. If he has a little understanding of the problem, he may be able to explain to you that the drifting to the right which you seem to see is really due to the fact that your system is turning out from under the moving balls.

The earth is a spherical merry-go-round, and all of the Coriolis drifts we observe when we use terrestrial co-ordinate systems are due ultimately to the fact that the earth, like the merry-go-round, is always spinning out from under our dynamical systems. To be sure, there are certain subtleties that enter into some Coriolis effects, but at bottom the whole thing is just the merry-go-round idea. To an observer conscious of Newton's second law of motion, the apparent "acceleration" (deflection from a straight path) of an object moving over the earth suggests that some force is acting on it, and he is strongly tempted to speak of the Coriolis "force." For convenience, meteorologists and others who are concerned with the Coriolis effect do treat it as a force, and their equations work out all right. What they set down as a force in the Newtonian equation is actually a correction for the apparent acceleration. The pure dynamicist looks at it in a different way: he likes to regard these motions as occurring in obedient Newtonian fashion in what he calls "inertial space."

Now let us look at some interesting examples of the Corio effect, as it applies to projectiles, flight, vehicles, ocean cu rents, and even our weather. The Coriolis effect is great near the North and South Poles (where the earth turns m rapidly under a moving object) and decreases to zero at t Equator. The magnitude of the effect also depends directly the speed of the moving object.

In middle latitudes of the Northern Hemisphere a bullet fir with a velocity of 800 feet per second at a target 400 feet aw will drift one-tenth of an inch to the right (without consid ing wind effects or any other interference). That is, in t half-second during which the bullet is in flight, the rotat of the earth has shifted the bull's-eye by about one-tenth of inch. This is not serious to a pistol marksman, but the eff can make quite a difference to a long-range gunner. A batt ship gunner who takes dead aim at the bridge of a destro 20 miles away and fires a shell at 2,500 feet per second w miss the destroyer completely, because the lateral Corio drift will be more than 200 feet. In World War I the shells the giant German gun called Big Bertha, which bombard Paris from a firing site some seventy miles away, took th minutes to reach their destination, and they underwent a Cor lis drift to the right amounting to almost a full mile—an err for which the German ballistics experts carefully allowed.

For a really dramatic effect we can take the case of a rock fired from the North Pole and aimed at, say, New York Ci Assuming, for the sake of simplicity, that the rocket travels a constant speed of a mile per second, it will be in flight f about fifty-five minutes. During all of this time the target, N York City, will be traveling at eighteen miles per second throu solar-system space (the speed of the earth's movement arou the sun) and will also be turning with the rotation of the ear at the rate of fifteen degrees of longitude per hour. As the res of these motions the rocket, at the end of fifty-five minutes, w come to earth in some cornfield in northeastern Illinois, not f from Chicago!

The earthbound observers who have been plotting the a parent path of this rocket with their radar network will s that it traced out a graceful curve which started out strai

south in the longitude of New York City, but veered steadily westward, arriving in Illinois from a direction about eleven degrees east of north. A less provincial observer out in interplanetary space will see that the effect is entirely a result of the earth itself having turned out from under the moving rocket.

This is an idealized case; in actual situations the Coriolis effect is much less evident, because other forces such as air resistance, neglected in this example, also act on moving objects. Furthermore, the motion of a projectile fired from any place on the earth other than the Poles would be influenced not only by the Coriolis effect but also by the initial impetus from the circumpolar rotation of the launching site.

An airplane experiences Coriolis drifts which would lead to astonishing errors in long flights if no compensation were made for them. A jet fighter that set out on a great circle heading from Chicago to New York and flew at 600 miles per hour without changing its heading would miss New York by several hundred miles to the south (assuming no allowance for any wind). And if the same pilot tried to fly in a similar way from Seattle to New York, he would find himself down in South America by the time he crossed the meridian through New York! In actual flights a pilot continually banks his plane slightly leftward, in our hemisphere, to compensate for Coriolis drift. It should be noted that, large as these deviations due to the rotation of the earth are, they are still small compared to the effects of cross-winds normally encountered in actual flights. The pilot's Coriolis corrections are thus obscured by the jockeying necessary to compensate for wind drift. To compensate for the Coriolis drift and keep a 20,000-pound jet fighter on a straight terrestrial course at 600 miles per hour requires a leftward force of about fifty-five pounds in middle latitudes of the Northern Hemisphere. This the pilot manages by manipulation of the plane's wings.

Railroad cars are much more massive, so the Coriolis reaction in their case is greater. A 500-ton locomotive moving at 60 miles per hour develops a lateral pressure on the rails amounting to about 300 pounds in middle latitudes. This has given rise to the story that the wheels on trains wear unevenly. Such a result could hardly be detected on coaches or freight cars, which

for railroading reasons have no definite right or left sides, an the Engineering Department of the Union Pacific Railroad ha informed the author that even in the case of locomotive whee the difference of wear on the flanges of the right and left whee is too small to be measured.

Why is so universal (one should say, "so terrestrial") an ef fect not readily apparent in our everyday activities? The an swer is that for many moving objects the tendency toward lateral drift is quite easily counteracted as the motions procee Thus in the case of the car speeding down the highway sixty miles per hour, the potential fifteen feet of shift per mi is prevented by the frictional resistance of the tires to later motion.

A walking man makes corrections for the Coriolis effe easily and quite unconsciously. On frictionless ice that pre vented his making any small lateral corrections (but someho still permitted him to walk!) a man walking at four miles pe hour would drift from his intended straight path by about 25 feet at the end of one mile. Lost polar explorers are reporte to have a strong tendency to circle steadily toward the righ near the North Pole and to the left near the South Pole; th may very well be due to the Coriolis effect, which is abo fifty per cent stronger at the Poles than in middle latitudes. I is said that even the penguins in the Antarctic waddle in arc to the left, but this the author will have to see to believe.

Among all the physical phenomena in which the Coriol effect plays a role, the most striking is the weather. Were not for the Coriolis effect, winds on the earth would rus directly from higher-pressure areas to lower-pressure one and no strong "high" or "lows" could develop. Hence the would be no opportunity for the build-up of the intense cyclon and the large anticyclones that control and give variability t our weather, and our weather would be much less changeab than it is. This is precisely the situation in the tropics, whe the Coriolis effect is zero or very small. In that almost Corioli free belt any atmospheric pressure differences produced by hea ing of the air at the ground are quickly smoothed out, and th region has well earned the name of "the doldrums." Hurrican and typhoons never form closer to the Equator than about fi

degrees of latitude.

Away from the Equator, however, the case is very different. There the Coriolis acceleration causes winds to veer around and blow at right angles to the pressure gradient, instead of parallel with it. The result is the pattern of strong lows and highs and circular movement that is responsible for changes in our weather.

On other planets, where the angular velocity of rotation is different from that of the earth, the Coriolis effect is correspondingly different. Jupiter and Saturn must have very marked Coriolis effects, because each rotates about two and a half times more rapidly than does the earth. Their atmospheres of hydrogen, methane, and ammonia must have very steep pressure gradients, if their winds compare in strength with ours. In contrast, the atmosphere of Venus is probably very calm, because Venus rotates much more slowly than the earth—perhaps once in about thirty terrestrial days.

Just as the motions of the atmosphere exhibit the Coriolis effect, so also do the more ponderous movements of the great ocean currents. To simplify the picture a bit, let us assume that the density of the sea is uniform. The oceans are not perfectly level, for the winds shift the waters and give them a gentle relief. Since water flows downhill, the natural tendency of the oceans' water is to flow from regions where the mean sea-level is relatively high to those where it is lower. But as soon as the water tries to move in so forthright a fashion, the Coriolis drift causes the moving water to veer off to the right (in the Northern Hemisphere). Eventually the currents flow steadily along the contour lines, with the water surface sloping upward to the right as one looks in the direction of flow. In practice, of course, internal eddy-stresses within the ocean and the winds blowing across the sea surface modify this trend. But the general rule still holds.

Lest the reader mistakenly conclude that he should have spotted these oceanic hills and valleys on his last sea voyage, it should be mentioned that the total difference of mean height across even the fastest-moving parts of the Gulf Stream system is only about a foot and a half in some eighty or ninety miles. Even this modest slope is only partly due to Coriolis effects,

the remainder resulting from the sort of horizontal densit gradients we have agreed to overlook. Yet, slight as such surfac slopes may be, they constitute a major factor in the dynamic of the ocean currents.

People on the Pacific Coast are well acquainted with ce tain other consequences of the Coriolis acceleration, thoug not many realize this is the cause. Coriolis drift is mainly re sponsible for the notorious California fogs and coldness of th water on California's beaches. Off the California coast, whe the prevailing winds are from the northwest, the wind stress an Coriolis drift generally combine to make the coastal wate sidle off in a southwesterly direction. As water is transporte away from the shore toward the southwest, the deficit mu be made up somehow. The water moving offshore is replace by water rising from below. This upwelling brings up wate from cold strata lying at depths as great as several hundre feet. As a result there is a cool strip of water along the Californ coast, superimposed, in fact, on the already cool Californ Current flowing down from the north. In summer the warm moist Pacific air streaming in from the northwest is cooled b the coastal water and this is what forms the fogs for whic California regrets to be famous. A similar situation prevai off the coast of Peru and parts of the western coast of Africa.

Some geologists believe the Coriolis effect causes a river t erode one of its banks faster than the other. The Russian sc entists P. A. Slavsov and Karl von Baer reported that rive valleys in Siberia tend to have steep walls on their left sid Similar asymmetries have been observed in some Alaska rivers, in the Missouri River and in a number of streams o Long Island. This supposed effect of the Coriolis drift is some times called Baer's law. But students of the effect have not a been willing to attribute it to the Coriolis influence. Even in river a mile wide flowing at the fast rate of five miles per ho in middle latitudes of the Northern Hemisphere, the Corio drift to the right would pile up the water only a little mo than one inch higher at the right bank than at the left bank. Po sibly such a slight difference in height might cause significa differences in erosion over geological periods of time, but th question is still unsettled.

This is as good a place as any to correct the persistent misconception that the Coriolis acceleration causes the water to run out of a washbowl in a clockwise direction in the Northern Hemisphere and counterclockwise in the Southern Hemisphere. The Coriolis influence is so small at the velocity of water in a washbowl, the time involved is so short and other factors are so numerous (hands, noncircular bowl-shapes, and so on) that one may feel sure the Coriolis effect is never in control here. This is regrettable, because if it were, a washbowl would constitute a useful analogue of a cyclone in the atmosphere.

We shall consider one more possible case of a Coriolis effect. There is a theory that some birds may be guided in their migrations by sensitivity to the Coriolis acceleration and to geomagnetic latitude. H. L. Yeagley of Pennsylvania State College has recently studied this amazing theory in an effort to determine the navigating techniques of the homing pigeon.

When a bird flies at constant ground speed in the Northern Hemisphere, its Coriolis acceleration toward the right grows greater the farther north it flies. Yeagley suggests that if, through some delicate sensory organ, the bird can detect slight differences in this acceleration, and can combine this information with an accurate estimate of its ground speed, it may be able to sense its geographical latitude. If, at the same time, another sensory organ with the necessary electrical properties senses differences in the minute electromotive forces generated by virtue of the bird's motion through the earth's magnetic field, then this plus the bird's estimate of its speed would provide a basis for sensing geomagnetic latitude. Now, since the magnetic poles of the earth are displaced some twenty degrees from the geographical poles, the parallels of geomagnetic latitude form a grid with the parallels of geographical latitude, and with this grid it is theoretically possible to navigate.

Most physicists would regard the theory as of very low *a priori* plausibility. Even assuming that a bird's senses are so delicate that it can detect the tiny differences in Coriolis acceleration and magnetic field, these cannot be translated into latitude until the bird has compared each effect with a very precise estimate of its ground speed. Furthermore, the bird must somehow allow for the effect of cross-winds, which is

normally much greater than the Coriolis drift. As if this were not enough, the bird would have to defy relativity theory, which says that it could not distinguish the effects of the normal atmospheric electric field from those induced by the bird's motion through the earth's magnetic field. Yet despite these difficulties certain features of Yeagley's theory seem to have been borne out by his extensive studies with homing pigeons.

If further research should confirm the magnetic-Coriolis theory of bird navigation, the solution of this deep mystery of the animal world will be rather more astonishing than the original mystery. It would certainly be startling to learn that this effect has been used by generations of golden plovers and Arctic terns to hold true to their courses as they fly over thousands of miles of trackless oceans.

Whether the birds are really that clever or not, we may be quite sure that they inexorably tend to drift as they fly. All things that move over the surface of our spinning earth, whether birds, winds, rivers, ocean currents, explorers, cars, trains, bullets, or rockets, are inevitably subjected to this effect as we view them in our terrestrial co-ordinate systems. Even when man gets away from his planetary home and stakes out better behaved co-ordinate systems in interplanetary space, he will not be able to omit consideration of the Coriolis effect from his dynamics. For the solar system itself, along with all its near neighbors, is slowly but surely rotating around the hub of our galaxy, some 30,000 light-years away. Undoubtedly a precise analysis of the waddling of Antarctic penguins would show not only Coriolis effects due to the earth's circumpolar rotation, and similar but smaller effects due to our planet's annual circuit around the sun, but also a tiny Coriolis drift due to the stately whirl of our solar system about the center of the galaxy.

Here we find ourselves in somewhat the same situation as Archimedes with his earth-moving lever—all *we* need to demonstrate our point is a suitable co-ordinate system.

JOSEPH BERNSTEIN

Tsunamis

There are few natural catastrophes more terrifying than "tsunamis" or, as they are better though incorrectly known, "tidal waves." (Tidal waves are caused by subsea earthquakes and have nothing to do with tides.) Since shortly after World War II, tidal waves have been subjected to close study by oceanographers. In this article, Joseph Bernstein of the U. S. Navy Hydrographic Office tells what has been learned and how a start has been made toward devising a warning system to prevent disasters such as befell the Hawaiian Islands one day in May, 1946. The article is reprinted by permission of the publisher from the *Scientific American*, August, 1954 (Vol. 191, No. 2).

On the morning of April 1, 1946, residents of the Hawaiian Islands awoke to an astonishing scene. In the town of Hilo almost every house on the side of the main street facing Hilo Bay was smashed against the buildings on the other side. At the Wailuku River a steel span of the railroad bridge had been torn from its foundations and tossed 300 yards upstream. Heavy masses of coral, up to four feet wide, were strewn on the beaches. Enormous sections of rock, weighing several tons, had been wrenched from the bottom of the sea and thrown onto reefs. Houses were overturned, railroad tracks ripped from their roadbeds, coastal highways buried, beaches washed away. The waters off the islands were dotted with floating houses, debris and people. The catastrophe, stealing upon Hawaii suddenly and totally unexpectedly, cost the islands 159 lives and $25,000,000 in property damage.

Its cause was the pheonomenon commonly known as a

"tidal wave," though it has nothing to do with the tidal forces of the moon or sun. More than 2,000 miles from the Hawaiian Islands, somewhere in the Aleutians, the sea bottom had shifted. The disturbance had generated waves which moved swiftly but almost imperceptibly across the ocean and piled up with fantastic force on the Hawaiian coast.

Scientists have generally adopted the name "tsunami," from the Japanese, for the misnamed tidal wave. It ranks among the most terrifying phenomena known to man and has been responsible for some of the worst disasters in human history. What made the 1946 tsunami especially notable was that a number of oceanographers happened to be in the Pacific (in connection with the Bikini atomic bomb test) and were able to observe it at first hand. It became the most thoroughly investigated tsunami in history, and from it came the development of an effective new warning system by the U.S. Coast and Geodetic Survey.

A tsunami may be started by a seabottom slide, an earthquake or a volcanic eruption. The most infamous of all was launched by the explosion of the island of Krakatoa in 1883; it raced across the Pacific at 300 miles an hour, devastated the coasts of Java and Sumatra with waves 100 to 130 feet high and pounded the shore as far away as San Francisco.

The ancient Greeks recorded several catastrophic inundations by huge waves. Whether or not Plato's tale of the lost continent of Atlantis is true, skeptics concede that the myth may have some foundation in a great tsunami of ancient times. Indeed, a tremendously destructive tsunami that arose in the Arabian Sea in 1945 has even revived the interest of geologists and archaeologists in the Biblical story of the Flood.

One of the most damaging tsunamis on record followed the famous Lisbon earthquake of November 1, 1755; its waves persisted for a week and were felt as far away as the English coast. Tsunamis are rare, however, in the Atlantic Ocean; they are far more common in the Pacific. Japan has had fifteen destructive ones (eight of them disastrous) since 1596. The Hawaiian Islands are struck severely an average of once every twenty-five years.

In 1707 an earthquake in Japan generated waves so huge

that they piled into the Inland Sea; one wave swamped more than 1,000 ships and boats in Osaka Bay. A tsunami in the Hawaiian Islands in 1869 washed away an entire town (Ponoluu), leaving only two forlorn trees standing where the community had been. In 1896 a Japanese tsunami killed 27,000 people and swept away 10,000 homes.

The dimensions of these waves dwarf all our usual standards of measurement. An ordinary sea wave is rarely more than a few hundred feet long from crest to crest—no longer than 320 feet in the Atlantic or 1,000 feet in the Pacific. But a tsunami often extends more than 100 miles and sometimes as much as 600 miles from crest to crest. While a wind wave never travels at more than about sixty miles per hour, the velocity of a tsunami in the open sea must be reckoned in hundreds of miles per hour. The greater the depth of the water, the greater is the speed of the wave; Lagrange's law says that its velocity is equal to the square root of the product of the depth times the acceleration due to gravity. In the deep waters of the Pacific these waves reach a speed of 500 miles per hour.

Tsunamis are so shallow in comparison with their length that in the open ocean they are hardly detectable. Their amplitude sometimes is as little as two feet from trough to crest. Usually it is only when they approach shallow water or the shore that they build up to their terrifying heights. On the fateful day in 1896 when the great waves approached Japan, fishermen at sea noticed no unusual swells. Not until they sailed home at the end of the day, through a sea strewn with bodies and the wreckage of houses, were they aware of what had happened. The seemingly quiet ocean had crashed a wall of water from ten to a hundred feet high upon beaches crowded with bathers, drowning thousands of them and flattening villages along the shore.

The giant waves are more dangerous on flat shores than on steep ones. They usually range from twenty to sixty feet in height, but when they pour into a V-shaped inlet or harbor they may rise to mountainous proportions.

Generally, the first salvo of a tsunami is a rather sharp swell, not different enough from an ordinary wave to alarm casual observers. This is followed by a tremendous suck of

water away from the shore as the first great trough arrive Reefs are left high and dry, and the beaches are covered wit stranded fish. At Hilo large numbers of people ran out to in spect the amazing spectacle of the denuded beach. Many o them paid for their curiosity with their lives, for some minut later the first giant wave roared over the shore. After an eart quake in Japan in 1793 people on the coast of Tugaru were s terrified by the extraordinary ebbing of the sea that they scu ried to higher ground. When a second quake came, they dashe back to the beach, fearing that they might be buried under lan slides. Just as they reached the shore, the first huge wa crashed upon them.

A tsunami is not a single wave but a series. The waves a separated by intervals of fifteen minutes to an hour or mo (because of their great length), and this has often lull people into thinking after the first great wave has crashed th it is all over. The waves may keep coming for many hour Usually the third to the eighth waves in the series are the bi gest.

Among the observers of the 1946 tsunami at Hilo wa Francis P. Shepard of the Scripps Institution of Oceanograph one of the world's foremost marine geologists. He was ab to make a detailed inspection of the waves. Their onrush an retreat, he reported, was accompanied by a great hissin roaring, and rattling. The third and fourth waves seemed t be the highest. On some of the islands' beaches the waves cam in gently; they were steepest on the shores facing the directio of the seaquake from which the waves had come. In Hilo Ba they were from twenty-one to twenty-six feet high. The highes waves, fifty-five feet, occurred at Pololu Valley.

Scientists and fishermen have occasionally seen strange by products of the phenomenon. During a 1933 tsunami in Japa the sea glowed brilliantly at night. The luminosity of the wat is now believed to have been caused by the stimulation of vas numbers of the luminescent organism *Noctiluca milaris* by th turbulence of the sea. Japanese fishermen have sometimes ob served that sardines hauled up in their nets during a tsunam have enormously swollen stomachs; the fish have swallowe vast numbers of bottom-living diatoms, raised to the surfac

by the disturbance. The waves of a 1923 tsunami in Sagami Bay brought to the surface and battered to death huge numbers of fishes that normally live at a depth of 3,000 feet. Gratified fishermen hauled them in by the thousands.

The tsunami-warning system developed since the 1946 disaster in Hawaii relies mainly on a simple and ingenious instrument devised by Commander C. K. Green of the Coast and Geodetic Survey staff. It consists of a series of pipes and a pressure-measuring chamber which record the rise and fall of the water surface. Ordinary water movements, such as wind waves and tides, are disregarded. But when waves with a period of between ten and forty minutes begin to roll over the ocean, they set in motion a corresponding oscillation in a column of mercury which closes an electric circuit. This in turn sets off an alarm, notifying the observers at the station that a tsunami is in progress. Such equipment has been installed at Hilo, Midway, Attu, and Dutch Harbor. The moment the alarm goes off, information is immediately forwarded to Honolulu, which is the center of the warning system.

This center also receives prompt reports on earthquakes from four Coast Survey stations in the Pacific which are equipped with seismographs. Its staff makes a preliminary determination of the epicenter of the quake and alerts tide stations near the epicenter for a tsunami. By means of charts showing wave-travel times and depths in the ocean at various locations, it is possible to estimate the rate of approach and probable time of arrival at Hawaii of a tsunami getting under way at any spot in the Pacific. The civil and military authorities are then advised of the danger, and they issue warnings and take all necessary protective steps. All of these activities are geared to a top-priority communication system, and practice tests have been held to assure that everything will work smoothly.

Since the 1946 disaster there have been fifteen tsunamis in the Pacific, but only one was of any consequence. On November 4, 1952, an earthquake occurred under the sea off the Kamchatka Peninsula. At 17:07 that afternoon (Greenwich time) the shock was recorded by the seismograph alarm in Honolulu. The warning system immediately went into action. Within about an hour, with the help of reports from seismic

stations in Alaska, Arizona, and California, the quake's epicenter was placed at 51 degrees North latitude and 158 degrees East longitude. While accounts of the progress of the tsunami came in from various points in the Pacific (Midway reported it was covered with nine feet of water), the Hawaiian station made its calculations and notified the military services and the police that the first big wave would arrive at Honolulu at 23:30 Greenwich time.

It turned out that the waves were not so high as in 1946. They hurled a cement barge against a freighter in Honolulu Harbor, knocked down telephone lines, marooned automobiles, flooded lawns, killed six cows. But not a single human life was lost, and property damage in the Hawaiian Islands did not exceed $800,000. There is little doubt that the warning system saved lives and reduced the damage.

But it is plain that a warning system, however efficient, is not enough. In the vulnerable areas of the Pacific there should be restrictions against building homes on exposed coasts, or at least a requirement that they be either raised off the ground or anchored strongly against waves.

3. Inside and Outside the Atom

J. BRONOWSKI

ABC of the Atom

This is the best, the simplest, and the clearest explanation of the atom that I have ever read. It appeared originally in the *New York Times Sunday Magazine* of October 28, 1951, and is reprinted with the permission of the *New York Times Magazine* and Dr. Bronowski. Dr. Bronowski, whom we encountered in the first section of this book (see "The Common Sense of Science") is chief physicist of the British Coal Board. The illustrations are reprinted by permission of the artist, James Lewicki.

Men have been talking about the atom now, off and on, for two thousand years. Yet to this day nobody has ever seen an atom; until twenty years ago, nobody had seen anything which even resembled an atom. Then why have we been so sure, all these two thousand years, that the atom was there, somewhere at the heart of matter, if only we could find it?

The reason, oddly, has little to do with scientific experiment and finesse. It is a solid logical reason, which remains as plain today as it was to the Greeks who first thought of it. If I put a lump of salt on my tongue, I know at once what it is: it tastes salt. If I crumble the lump into grains and taste only a grain, I still know it to be salt. If I put the grain under the microscope and pick it apart into its tiny crystals, each crystal is still salt and nothing else. We can shatter the little glittering crystal into

smaller crystals; the process of breaking can go on and on; but it is not conceivable that it can go on forever.

There must be a smallest unit of salt beyond which we cannot go if we want still to have salt. There must be a tiniest unit of sugar which remains sugar, and in the same way there must be characteristic units of every substance—iron and the green chlorophyll in leaves, and pencil lead and vitamin B_{12}. A patient may be cured of pernicious anemia by as little as a millionth of an ounce of vitamin B_{12}. But still there must be a smallest piece of the vitamin which makes it B_{12}.

This is the picture of matter which we have had since the Greeks. A substance is made up of tiny pieces, each of them itself indivisible, each alike, and each characteristic of that substance and not something else. The Greeks called these pieces atoms, which means "indivisible."

It is important to begin this way, historically and logically. For this makes us aware that our idea of an atom starts from common sense; it is based on everyday notions and experiences which we all share. Of course, we have to go on from these to more modern and detailed conceptions. But even those, we must remember, are attempts to find simplicity and order in the bewildering variety of natural substances. Never believe that the atom is a complex mystery—it is not. The atom is what we find when we look for the underlying architecture in nature, whose bricks are as few, as simple, and as orderly as possible.

With that, we are ready to begin our questioning of nature.

What Is an Atom?

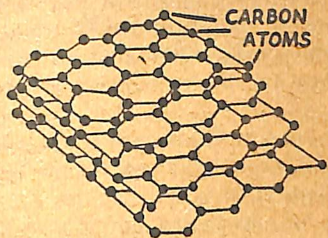
An atom is the smallest piece of an elementary substance which is characteristic of that substance and not something else.

This is still the Greek answer, but we have narrowed it by adding one word—the word "elementary." The Greeks only thought of cutting up a lump of salt physically. We have learned in the last hundred and fifty years that it can also be taken apart chemically, reduced to two more elementary substances, sodium and chlorine. Therefore nowadays we distinguish between com-

pound substances, which can be taken apart chemically, and elementary substances, which cannot. We reserve the word atom for the smallest unit of one of these elementary substances.

Here is a picture of the atoms in the elementary substance, pencil lead:

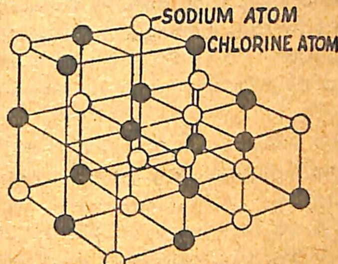
GRAPHITE PARTICLE



They are all alike, for they are all atoms of carbon. They are stacked neatly in sheets. And in each sheet they make a honeycomb of six-cornered cells.

And here is a picture of a crystal of salt:

SALT PARTICLE



The two elementary substances of which it is compounded have each their own atoms. They build up a strong square framework in which each kind of atom locks the other into place.

Where Are Atoms Found?

Every substance is built up of atoms, either all of one kind or a linked arrangement of several kinds. Therefore, atoms are found everywhere where there is matter.

In a solid, atoms are arranged tidily as our pictures show. When the solid melts into a liquid the atoms wander from their neat stations, but they are not lost. And when the liquid boils up into a gas, the atoms dart about and take up more and more space. But the atoms are still there, everywhere, in solid, liquid, and gas.

The air in your lungs at this instant is made of atoms—about 10,000,000,000,000,000,000,000 of them. This will do as a figure to end all figures. It is, for example, a good deal more than the number of cells in the brains and bodies of all the 2,500,000,000 inhabitants of the world today, added together. It reminds us that the scale of the pictures we have just drawn is very large, that the atom is very small, and that it has no trouble in getting anywhere.

Do Atoms Vary?

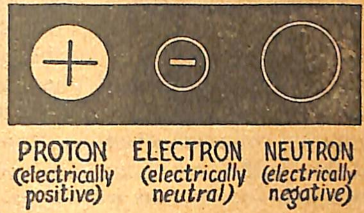
This is the $64 question. Of course the answer is "Yes, indeed." The atoms of one elementary substance are different from those of another. There are therefore as many kinds of atoms as there are elementary substances—about one hundred in all.

But this answer wins no prizes—yet. For the crux of the question lies deeper: in what way do the atoms vary one from another?

Sixty years ago we had no idea. Each kind of atom was permanent, indivisible, and different from every other: that was all we knew. Only since then have we discovered, slowly, step by step, and with mounting astonishment, that under this variety lies a deeper unity. Nature, which has built its wealth of compounds, rocks and proteins, ores and sugars and living bones, all from only one hundred atoms—nature has a still

more profound economy. For each atom itself has a structure—and a much simpler structure.

All atoms are assembled from three kinds of fundamental, electrical particles. They are:



It would be elegant if these fundamental particles were all equally heavy; but they are not. The proton and the neutron are heavy particles—each has almost 2,000 times the mass of an electron—but even they are not quite equal. And the electron is so light that it really seems to be nothing but a tiny charge of negative electricity.

Atoms vary only in the number of fundamental particles from which they are assembled.

Now we see that the question, Do atoms vary?, does indeed take us very deep. For hitherto we have looked at the atoms which make up matter only from the outside. Now we must go to the heart of matter—into the atom itself.

What Is the Atom's Structure?

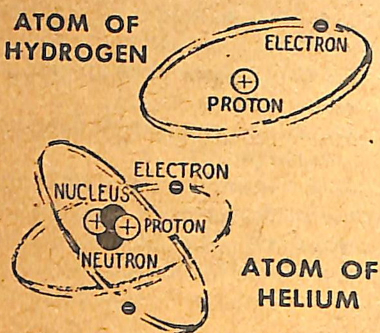
Every kind of atom has essentially the same structure. At the center there is a heavy kernel or nucleus; all the heavy particles in the atom are concentrated in this. Away on the outskirts of the atom are the light electrons.

The electrons are in constant movement. They circle around the nucleus much like the planets circle around the sun. But their orbits are less precise, so that they form a kind of spinning cloud or shell.

In fact, the electrons are only the outriders of the atom. They are lost and recovered, they wander off in an electric current, but still the atom remains essentially the same. For the solid substance and anchor of the atom is its heavy kernel or nucleus.

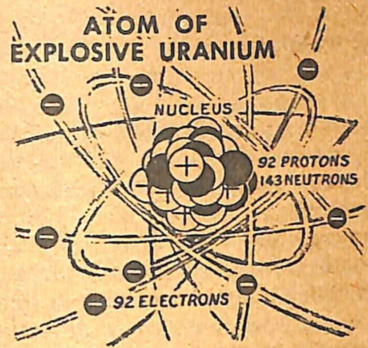
The nucleus is made up of protons and neutrons, tightly bound together. Their numbers are characteristic of each kind of atom. In particular, each elementary substance has a characteristic number of protons in its atoms. The nucleus of hydrogen has one proton, the nucleus of helium has two, and so on up the scale of nature to uranium, whose nucleus has ninety-two protons. Beyond this lie the new elements which man has created in the atomic pile—neptunium with a nucleus of ninety-three protons, plutonium with ninety-four, and higher still.

Here are pictures of these atoms:



The atom of ordinary hydrogen has only a proton for its nucleus and, to balance its electric charge, one electron circling around it. The atom of helium has a nucleus of two protons and two neutrons bound together; their electric charge is balance by two electrons which circle around the nucleus at a distance.

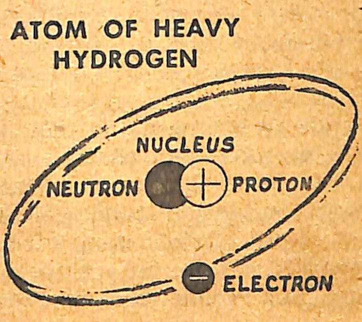
And here is a picture of the atom of explosive uranium:



The nucleus is made up of ninety-two protons and 143 neutrons, and by way of electrical balance there are, on an average, ninety-two electrons circling on the outskirts of this atom.

The picture of an atom of ordinary uranium would be the same, except that there would be three more neutrons in the center. For the two kinds of uranium are merely variants or isotopes of the same element, and isotopes differ by a few neutrons but nothing else.

For example, even the nucleus of hydrogen may have an extra neutron. This makes the atom into heavy hydrogen, which is a variant or isotope of hydrogen. Here is its picture:



What Is Atomic Energy?

The structure of the atom is held together by invisible forces. For example, there is an electrical attraction between the positive nucleus and the negative electrons. But this is a modest force, no more violent than that with which our sun holds the planets in their orbits.

The greater energy lies like a coiled spring in the nucleus itself. For the nucleus is full of protons which are all electrically positive, and which ought therefore to repel one another with enormous forces. Somehow these electrical forces are held in check: an unknown binding energy which we do not understand welds the protons and the neutrons into a single stable kernel.

Therefore, atomic energy is nuclear energy. It is the binding energy which holds the nucleus together, and checks the electrical repulsions which would make it fly violently apart.

How Is Atomic Energy Released?

The nucleus of every atom is very stable. But some of the heavier atoms do from time to time fire off a part of the nucleus of their own accord. These are the naturally radioactive atoms, such as radium and uranium. In them, the nucleus tries to simplify itself spontaneously to a more stable form. For the most stable nucleus is neither among the very light nor the very heavy elements, but about halfway between.

Whenever a nucleus rearranges itself in this way, from a less stable to a more stable structure, it releases some of its binding energy. All that we need to do is to offer the nucleus the chance, as it were, to rearrange itself: the energy will then fly out of itself. To offer it this chance we deliberately make the nucleus unstable, by striking and invading it with an extra proton or neutron. A proton has been used, but it has to be fired with great energy itself, because the positive nucleus repels its approach. The ideal tool to split the atom is the neutron, for

has no electrical force to overcome on its way to the nucleus.

When a neutron strikes a heavy nucleus it may invade it and make it unstable. The nucleus then breaks up to a more stable form. A nucleus which so rearranges itself from a less to a more stable structure releases some of its binding energy of itself.

Oddly, the rearrangement of the nucleus can be weighed: the parts now weigh less than the whole nucleus did before. The loss of mass exactly balances the energy which has been released—as Einstein foretold nearly fifty years ago.

What Is Fission?

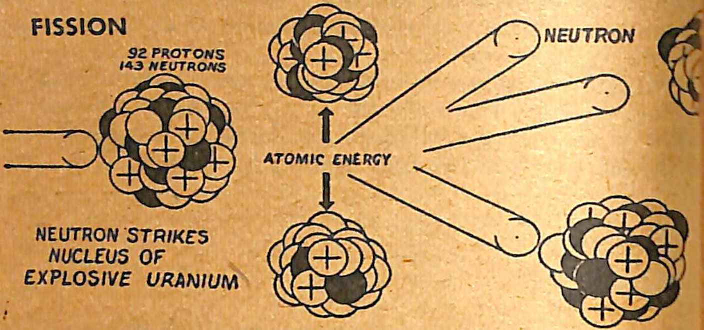
Fission is the breaking apart of atoms. It is brought about, as we have just seen, by striking a heavy nucleus with a neutron which invades it and makes it unstable.

But so long as we have to fire neutrons one by one, and break up atoms one by one, we can only get energy in penny packets. To make the breaking or fission of atoms worth while, we need a reaction which fires off neutrons of itself as it goes along. Such a reaction was discovered late in the nineteen-thirties in the breakup of the explosive variant of uranium.

This is a remarkable reaction whose precise sequence in part remains secret. But what makes it remarkable is no secret. When this nucleus is struck by a neutron (see the drawing on page 114) the nucleus breaks up in such a way that, in addition to two roughly equal halves, it also fires off several of its own neutrons. These fly through the rest of the material, and if the piece is large enough each neutron is certain to strike another nucleus and thus set off another burst of energy—and fire off still other neutrons to carry on the reaction.

Therefore, the fission of heavy atoms gives a large return of energy only if it carries itself on from atom to atom in a continuous chain. To do this, each nucleus which breaks up must itself fire off several of its own neutrons. The atoms which do this most violently are the explosive variant of uranium

which was used in the Hiroshima bomb, and man-made plu-
nium, which was used in the Nagasaki bomb.



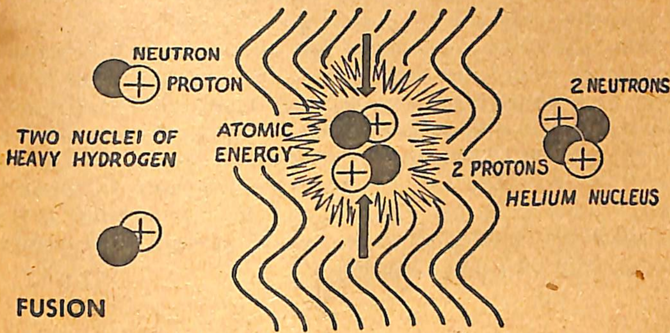
What Is Fusion?

A heavy nucleus which breaks up releases some of its bin-
ing energy because each of its halves is a more stable nucle-
The middling atoms are in fact more stable than the hea-
atoms; and they are also more stable than the light atoms.

It is therefore possible to rearrange several light atoms s
that they form a more stable nucleus, and to gain energy
this way. This is the building up or fusion of atoms.

The sun gets its heat in exactly this way, by the building
fusion of atoms. The sun and the stars use hydrogen as th
raw material, and by a step-by-step process running at twen
million degrees Centigrade, they fuse atoms of hydrogen in
a single helium nucleus. Ten years ago this process was beyo
our dreams, because we could not hope to reach on earth te
peratures measured in millions of degrees. But now the atom
bomb gives us a temperature of fifty million degrees for
millionth of a second, and this may be long enough to fire a m
ture of heavy hydrogens and fuse them explosively into h
lium.

Below is a picture of how the process might work in a bomb made of heavy hydrogen.



The helium nucleus is a little lighter than the two parts that go to make it up, and is more stable. Once again the loss of mass is turned into extra energy which we can use.

Can Atomic Energy Benefit Man?

The answer to this question is blunt: it can and it does, now, today, and every day. Few people grasp this, even when they see it in print, because few people are yet at home in the language of atoms. And just this is why the language is worth learning.

What can an atomic pile do for us that is good? The pile is a concentrated source of neutrons. It uses these neutrons to turn ordinary uranium into explosive plutonium. But in the process, it gives out heat: and this heat is already being used for daily civilian purposes. It will soon be used as a source of power, to drive an engine or to generate electricity. There are desert places where no other way of generating electricity will do; to them the atomic pile could bring power and irriga-

tion, and make the desert bloom.

But the neutrons in the pile are more than a source of power. They are also a source of radioactivity. The piles are today making radioactive cobalt and iron and iodine, which are helping to cure tumor patients every day. These radioactive cures are already a living part of good hospital practice.

The radioactive substances from the pile have another use in medical and industrial research. By putting them into a plant or a machine we can, as it were, see growth and wear and all changes with new and infinitely sensitive eyes. The Geiger counter has become the eye of research, which picks up and traces the movement of radioactive atoms moment by moment. Today these so to say visible atoms tell the scientist how a wound heals, what goes to fill an ear of corn, and whether grease really gets into a bearing.

The Future of the Atom

The wealth of the atom is here, in our hands and at our fingertips. If we do not reach it today we shall tomorrow. It is a power which we have made for ourselves, by experiment, by skill and search, but above all by thinking. The Greeks did not see atoms; they thought about them. Einstein, at twenty-six, did not change mass into energy; he thought about the laws of nature, until he saw that mass and energy must be interchangeable forms of the same essence in nature. His thought comes true every time a heavy nucleus yields energy by fission, or a light nucleus yields energy as it is built up by fusion. What use we make of this atomic energy is for us to choose. This is not a matter for scientists but for every citizen. The scientist can only offer the gift; the citizen must understand it in order that he may fulfill it. Einstein had been a lifelong pacifist when in August, 1939, at the age of sixty, he wrote to tell President Roosevelt that an atomic bomb could probably be made. His scientific insight was right; he offered it, and he left the use and the decision to the nation.

Three years later, an atomic pile was turning ordinary uranium into plutonium on a squash court in Chicago. The

pile was not a weapon of war; it stood at a crossroads between peace and destruction. In medical and industrial research, in actual radioactive cures, and in the production of power, the atomic pile has now done as much for peace as for destruction.

For neither the fission of plutonium nor the fusion of hydrogen into helium are one-way roads to death. Like every great discovery, they offer an equal potential of happiness or disaster. They are the gift of science, and every scientist searches his heart at midnight to pray that the gift will bring a blessing. The prayer is in all our hearts; its fulfillment lies in all our hands.

A. W. MARTINEZ

Atomic Shooting Gallery

Much of the information about the structure of the atom given in the last article was obtained by the expedient of bombarding atoms with helium nuclei and other subatomic particles. I almost said "simple expedient," for the bombardment of atoms with subatomic particles is a simple idea. In practice, however, atomic bombardment has become an extremely complex procedure employing some of the most formidable machines ever built by man, the "particle accelerators" or "atom smashers." A description of the principal types of atom smashers now in use and how they work is given in Mr. Martinez's article, which together with the illustrations is reprinted with permission from the February, 1954, issue of *Steelways*, the magazine of the American Iron and Steel Institute. The late Mr. Martinez was a free-lance writer who wrote often on science and technology.

To most of us, the words "atomic explosion" conjure up picture of limitless destruction or limitless power. But to sc entists, some of our most important atomic explosions hav taken place in a laboratory and were both invisible and soun less.

With their atom smashers, or "particle accelerators" as th are called, nuclear scientists are taking atoms apart and explor ing the fundamental nature of matter and energy.

Out of this work may come momentous achievements suc as the discovery of a source of cheap and near-limitless powe

Atom smashing experiments are carried out by means

circular steel shells called "cyclotrons" and "synchrotrons," and artillery-like chambers known as "linear accelerators." The smallest fills a good-sized room; the largest a block-square building. The research projects are backed by millions of dollars of government and private funds, and the work is so important that many of our best physicists are devoting full time to it.

Although the equipment is complex, the principle of atom smashing is simple. The target is a few billion atoms—beryllium, copper, even hydrogen—and the bullets may be lightweight electrons or heavy protons. To smash atoms you "shoot" particles at them. If you shoot enough particles, you are sure to knock many of the atoms into smithereens—or neutrons, mesons, etc., as atomic smithereens are called.

An atom smasher is something like a gun. It uses electric attraction and repulsion in place of powder, and its "barrel" is a magnetic field instead of rifled steel; but like a gun it shoots "bullets" with speed and accuracy.

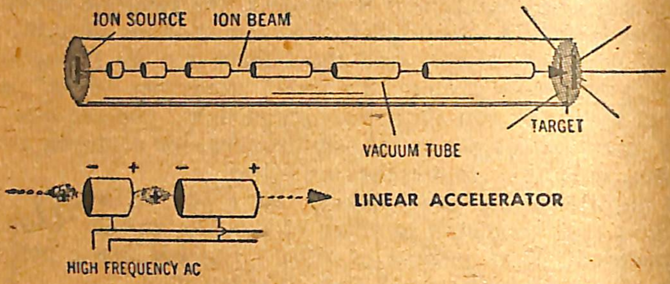
One of the simplest of the particle accelerators is a Van de Graaff—a big steel cylinder with a domelike steel protuberance at one end, all enclosed in a housing. One or two traveling belts inside the cylinder carry charged particles to the dome, where they build up an electrostatic charge. When the charge is high enough a quantity of proton bullets is fed into a central tube. The positively charged protons instantly come under the influence of the huge positive charge on the dome. Since positive repels positive, they are booted down through the tube, and come out the other end with an energy of a few million electron volts, called MEV in the scientific trade.

A linear accelerator is a sort of third cousin once removed from a Van de Graaff. Here again a large cylinder is used, and again there is a source of protons or other particles to be used as bullets. But instead of receiving one tremendous push the bullets are given several small pushes.

In the center of the big cylinder is a series of tubes arranged in line. The first tube is short, the second one is a little longer and so on to the end.

If positively charged particles—protons—are used for bullets, the first tube has a negative charge when the protons are

fed into the cylinder. Since negative attracts positive, the cloud of protons is pulled into the end of the tube with a sudden tremendous acceleration. But just as they enter the tube its charge is changed to positive, and now the protons are repelled with a sudden push which sends them blasting out toward the second tube. This technique is repeated to the end of the cylin-



Linear accelerator generates atomic bullets by kicking particles through a line of vacuum tubes with blasts of energy.

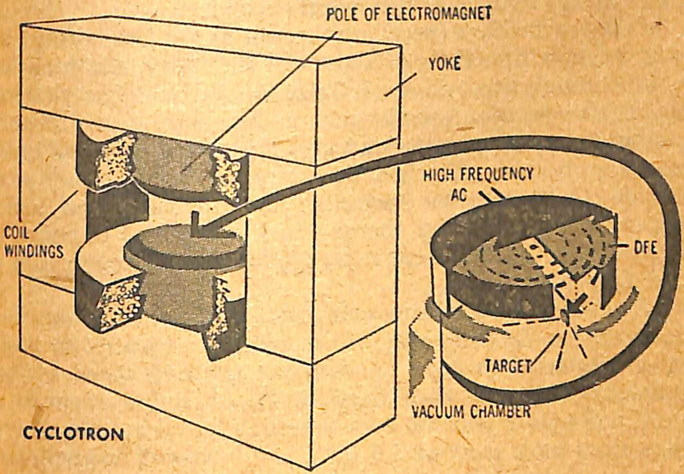
der. A linear accelerator can be built to fire protons against a target with an impact of one billion electron volts—one BEV —or more.

Utilizing the same principle of small nudges, scientists have also produced a monster called a cyclotron. A cyclotron is impossible to describe because it looks like nothing else but a cyclotron. But from the diagram you can see that it bears a faint resemblance to a huge pillbox, split in the middle, and slipped between the poles (top and bottom) of a gigantic electromagnet.

Particles are fed into the space between the two hollow parts of the pillbox—scientists with a burst of inspiration called them "D's"—and they immediately come under the influence of two powerful forces. One is an accelerating force between the D's which is produced by controlling the D's so that when one is positively charged the other is negatively charged. These charges alternate millions of times per second. The resulting force

whirls the particles around in a spiral inside the two D's, giving the speeding bullets a lusty kick each time they pass the gap in the middle. But as they gain speed, they also travel a longer path, getting farther out on the spiral. Thus they always take the same time to get back to the gap between the D's.

The other force, which keeps them in the spiral, is produced by the magnetic field set up between the poles of the electro-



Cyclotron pulls particles around inside two hollow "Ds," speeding them up with jolts of energy each time they pass the gap between the "Ds." Particles are held in a curved path by an electromagnetic field.

magnet. The tightness of the particles' spiral path depends on the strength of the magnetic field. The practical upper limit to which particles can be accelerated in a conventional cyclotron is about 25 MEV. Kick them faster than that and they get out of step and are lost.

But electronic improvements have gotten around this problem so well that cyclotrons can now develop energies of 400

MEV, and the largest one at the University of California (wher cyclotrons were first developed) is being modified to reach 75 MEV.

Next comes the synchrotron, and here things really begin t hum. In this doughnut-shaped creation, particles travel in fixed circle instead of a spiral. Their path is a small chann which passes through a circle of magnets. Imagine a tunn inside a doughnut, with the doughnut itself made up of magnets The magnetic field holds the speeding particles roughly in th center of this channel as they whirl around.

In the synchrotron (popularly known as the Cosmotron) Long Island's Brookhaven National Laboratory, the partic get their initial energy from a full size Van de Graaff accelerat which feeds protons into the channel in well-regulated burs sending them whipping around at a brisk pace. But this bris pace is soon revealed to be only a morning stroll as they pa through a sort of collar encircling the channel at one poin This collar has a positive charge which is changed to negativ as the cloud of protons enters it, pulling them through with powerful surge.

Each time they get this sudden pull treatment the partic accelerate, so the frequency of change from negative to pos tive is increased to keep up with the growing speed of th particles traveling in their fixed circle. All this happens in hurry, and before you can do a thorough job of batting an ey the protons have reached 2.3 BEV and have collided with th target, producing havoc in more than one unhappy atom.

In the works now is a sort of "super synchrotron." It w employ magnets with a strong focusing action capable of herd ing the speeding particles along in a tighter channel, and w have several accelerating collars instead of one. The first o built will probably reach 25 BEV, and there seems to be noth ing serious in the way of building a 100 BEV machine, exc money.

To get a more intimate view of a particle accelerator, le pay a visit to Brookhaven. Looking down upon the Cosmotr from the glass enclosed control station is like gazing into so silent world of the future. Nothing stirs around the great c of steel or on the brightly lighted floor surrounding it. Nothi

breaks the tense stillness except the toll of a bell sounding off the seconds. Yet within the measured space of each second uncountable tiny worlds meet in collision, disintegrate and in nearby research equipment leave behind an indelible record of their flight.

It takes 288 C-shaped blocks of steel, each eight feet high and eight feet wide, to form the Cosmotron doughnut. If you were to examine a cross section of one of these blocks you would find a thin rectangular channel surrounded by the magnet and wires. It is in this channel or shooting gallery that protons are whipped up to an energy of 2.3 BEV.

The business end of the Cosmotron lies below the control station. It is here that the Brookhaven research men place their targets. Today they use small slabs of ordinary material such as copper or graphite, but they soon expect to use liquid hydrogen as a target. That will give them isolated proton nuclei to shoot at and may well help to solve a number of nuclear mysteries.

Researchers have a simple method for sorting out the cosmic particles resulting from successful collisions. When a speeding proton strikes an atom, particles called neutrons can be made to stream from the target in a straight line and interact with the silver and carbon atoms of photographic plates. In the collision, mysterious particles called mesons squirt out of individual neutrons or protons in a kind of shower of shooting stars.

Not even a whole atom is visible, much less a meson which is about a million times smaller. Yet researchers at Brookhaven can detect mesons with scintillation counters similar to Geiger counters. Or they may photograph them in action with ponderous instruments called cloud chambers where mesons leave a telltale trail of ionized particles behind them when they pass.

When scientists build an accelerator of twenty or more BEV and send particles crashing into targets with this enormous energy behind them, they do not know what they will discover. The radiation laboratory of the University of California (like Brookhaven, sponsored by the Atomic Energy Commission) will soon be operating the Bevatron, a double-sized Cosmotron, to produce proton energies in the range of 5 to 7 BEV.

By using still larger machines to do still greater violence to

the atom, scientists will seek new answers to the riddle: what mysterious forces hold the nucleus together? When man really understands these forces he will be well on his way to mastering his world.

A. M. LOW

Feeling with Electrons

When I first set to work on this anthology, I hoped to be able to include in it a general article on electronics, the fabulous branch of technology that has grown up around the vacuum tube. Electronics (which may be defined, very roughly, as the control and utilization of electric currents with the aid of vacuum tubes and related devices) has got too big, however, to be put in a single article. It has not only brought us radio, television and long-distance telephone, but it guides our planes and ships, aims guns, cures plastics, runs factories and performs too many other tasks to mention. And the future will be even bigger, thanks to the transistor, the remarkable new gadget that is even handier than the vacuum tube (see "Little Gadget With a Large Future" in the last section of this book).

I had to settle for an article that covered just one of the applications of electronics. The article selected tells about radar. It is condensed from a chapter in *Electronics Everywhere* by A. M. Low and is reprinted from the 1952 American edition by permission of the John Day Company. Professor Low is a well-known British inventor in the radio field (he built and flew the world's first radio-controlled robot airplane) and a popular writer on science.

Two terms in the article may prove puzzling to American readers. "Valve" is British for vacuum tube, and an "electric fire" is an electric heater.

Most people have, at some time, stood in front of a cliff or wall, or even over a deep well, and shouted in order to hear the echo. The sound waves made by your voice travel to the cliff or wall, are reflected by the hard surface and travel back, now rather fainter, to be picked up by your ears. If you had an extremely

accurate stop-watch and could measure the time that elapsed between your shout and the hearing of the echo, you would have a method of estimating the distance away of the wall. Knowing that sound travels at about 1,100 feet a second, you would simply have to estimate how far sound would travel in the measured time and then halve it to find the distance away of the object.

As a matter of fact, this method of "sound ranging" is used in practice for a number of purposes. Sounds generated in water are used for measuring the distance away of the bottom of the sea. In the "echo sounder," the sound of a hammer travels to the sea bed and then back to the hull of the ship where it is picked up by a hydrophone, the time taken for the double journey giving the distance the sound has traveled, half of which, of course, is the depth of the water under the ship's keel.

In much the same way the distance away of a submarine or even a shoal of fish can be measured, but we have the additional complication of determining not only the distance of the object, but its direction. This is done by rotating the hydrophone and reading off the angle at which it received the maximum amount of sound, that is, the direction from which the reflections are strongest.

It is useful to explain the principles of "sound ranging" or, more correctly, "echo sounding," because the way in which electrons serve to discover the distance of objects that cannot be seen is very similar. The devices by which electrons are used to determine the distance of objects were first made in Britain and called generally "radio-location," a better name, perhaps, than "radar" as it is now generally termed, because what happens is that location is discovered with the aid of radio. Like sound, radio waves are reflected by anything which is an electrical conductor. Like sound waves, they also travel at a constant velocity although very much faster, something like 186,000 miles a second as compared with less than one-quarter of a mile a second for sound. As with sound waves, the echo of radio waves can be picked up, and, by measuring the time interval that has elapsed since the original signal was sent out, the distance of the reflecting surface can be calculated.

This is the principle of radar. But measuring distances by

radio waves seems rather complicated because the time intervals to be measured are so short. An ordinary stop-watch would, of course, be quite useless. It is difficult enough to measure one second accurately, and in this time the radio waves would, at least theoretically, have traveled seven times round the world. We have to think in terms of thousandths or even millionths of a second and the time-measuring devices are quite different from those used with sound. Indeed, it is only by using electronic devices, working at the same high speeds as the radio waves themselves, that we are able to measure the very short time these take to travel a mile or shorter distances. Incidentally, before we finish with the comparison with sound echoes, perhaps it should be noted that just as if you stand too close to the cliff you cannot hear any echo, so with radar you cannot locate any object that is very close. We do not hear the echo when near the cliff, not because the sound is not reflected, but because the reflection takes place so quickly that outgoing sound and reflected sound become mixed. If you could make a "short" enough sound, you would hear the echo even at a distance of ten feet.

It is very much the same in the case of radar. If the reflection takes place too quickly, the time interval becomes too short to measure, and some of the reflections are back before the last of the outgoing signals have left. If we work out the extremely short time that radio waves need to cover fifty yards, being only the same as light could take, it is easy to appreciate what a remarkable feat it is to make instruments able to measure this time for locating objects at so short a distance.

Radar is really a special form of wireless, perhaps much nearer to television than to radio-telephony, but different in important details from both these systems. One of the ways in which it differs is that transmitter and receiver are in the same place instead of being many miles apart. Carrying on the comparison with sound echoes, it is essential that your mouth, making the sound, should be near your ears which catch the reflected sound or echo. In most radar devices the transmitter and receiver even share the same aerial, using it alternately for millionths of a second at a time.

Another great difference is that whereas in sound and tele-

vision transmissions the transmitter radiates energy continuously, in radar it radiates the energy only in very short and powerful bursts. If when standing in front of your cliff you sang a loud and continuous "Ah . . ." you would not hear the echo and not be able to measure the interval. You must shout "Ah!" very sharply. So with radar, in order to be able to pick up the reflection you must make a short signal and then be silent for long enough for the signal to travel to the reflecting surface and back before the next signal is begun. There is another reason why the transmission is by short bursts, called "pulses," instead of continuously. It enables the energy of a comparatively small transmitter to be saved up and then suddenly packed into one powerful pulse. The signal must be strong to get a reflection since only a small part of the energy strikes the "target." Many radar transmitters send out a signal three times as powerful as the largest B.B.C. transmitter. Yet, because the energy is concentrated in short "bursts," they can be housed on a single truck and use comparatively small amounts of current.

The aerial system, also, is quite different in radar from that used when broadcasting. You may have seen the great aerials used for broadcasting or trans-Atlantic radio-telephony. Compare them with the typical radar aerial which can be carried on top of a truck or at the mast-head of a battleship and be little larger than the copper bowl of an electric fire. Radar aerials are highly directional. That is to say, they are designed to send out or receive signals only along a very narrow path or "beam." A broadcasting station radiates its energy in all directions, and the aerial of your receiving set is designed to pick up radio waves coming from everywhere, but a radar aerial is designed to keep its signals within the narrowest possible path and the receiving aerial also is designed to exclude all signals except those coming from one particular direction. Without this, we could not get "location"; we might know that there was an obstacle in the way of the radio waves because they were being reflected, and we might even be able to measure the time taken for reflection and so know the distance of the obstacle, but we should not be able to say whether it was east, west, north or south of the radar installation.

The "beaming" of the radio waves, or, more correctly, pulses

also enables more energy to be concentrated. Referring once more to the rough analogy of a sound echo, it is like cupping your hands round your mouth to make a shout carry farther, or holding your hands round your ears and turning your head to catch the faintest possible echo. Your head can turn to catch sounds coming from a particular direction and in the same way radar aerials are not motionless like broadcasting aerials, but able to move so that the direction of the transmitting beam of pulses can be changed and the direction of the reflected pulses more exactly located.

That is an outline of the principles on which radar works. It would be quite impossible to carry it into practice without the aid of a great variety of electronic devices in which countless millions of electrons produce the pulses, catch the echoes and measure the direction from which they are coming and the time they have taken. A radar installation may be quite a small instrument, less than a cubic foot in volume, or it may be an immensely complicated system with more than one hundred valves and hundreds more of other components. During the war, some scores of different types of radar installations were produced in very great numbers and it would be impossible to describe all in detail. We can, however, examine the different parts which all radar installations have and then see how these were adapted to the particular needs of specialized plants.

The beginning of every radio signal is electrical energy. In a radar set this may come from the "mains" if it is convenient, from a dynamo driven by a motor on a car or an airplane, or from batteries. The current feeds a modulator and, through it, an oscillator. The radio frequency oscillator produces the "pulses" or short bursts of radio waves at the desired frequency and the modulator supplies the necessary voltage only at intervals. The modulator "turns on" the oscillator which for about one-millionth of a second produces very powerful oscillations, after which it is turned off for a relatively long time, a matter of thousandths of a second, to give time for the pulses to reach the target and return.

The oscillator unit may be a single electronic tube or a number working together and it is the "heart" of the radar installation. Half the battle to perfect radar devices lay in designing an

oscillator which would produce very powerful oscillations. The design of low-powered high-frequency oscillators developing a few hundredths of a watt presented no great difficulty, but the construction during the war of oscillators able to produce one or two thousand kilowatts was the key to the precision radar sets which could show up even a piece of floating wreckage on the sea several miles away in total darkness.

The pulses are carried to the transmitting aerial, not by wires as in the ordinary radio transmitter, but by a cable of a special type suitable for carrying very high frequency impulses or more often by "wave guides," which are really pipes having proportions which are very carefully determined in accordance with the wave length, or rather the frequency, being used. These pipes are popularly called "plumbing."

A few special points about radar aerials have already been mentioned. To render the transmitting aerial highly directional, it may be built up in a large bowl or "concave mirror" which concentrates most of the energy in one narrow beam just as a searchlight mirror directs the light. Or a series of small aerials may be arranged so that all the energy is concentrated in one direction. There is no question of merely using a piece of wire of about the right length as with a home radio receiver. Measurements have to be exact and the whole system very efficiently designed, for we cannot afford to lose any of the energy that may be reflected from as much as fifty or sixty miles away.

The aerial determines the shape of the beam of pulses that is sent out and this can be varied for various purposes. For example, by making an aerial longer in one direction than in another, we can obtain a fan beam. We can have a beam that is flat and thus measures heights accurately or a beam that is vertical which will measure direction more accurately. Clearly the ability of a radar installation to distinguish between two objects close together will depend upon the sharpness of the beam. If the beam is not sharp two objects several hundred yards apart might, at a range of a few miles, return echoes that suggest a single large object. It is important, therefore, to have an acute beam which again depends upon the relative size of the aerial and wave length of the pulses. With an aerial of given size, the sharpness of the beam increases as the wave

length decreases. The tendency has, therefore, been toward shorter and shorter wave lengths. From the wave lengths of several meters used in the early radar installation we have come to "centimetric" radar in which wave lengths are measured in centimeters rather than meters. Instead of the wave lengths of two hundred to five hundred meters common on broadcasting transmitters, wave lengths in radar are often of a few centimeters only. For a beam as sharp with the longer wave lengths, we would need an aerial system so large that it would be quite impracticable.

If the aerial remained in one position all the time, echoes would only be received from things which fell within the narrow beam. Arrangements, therefore, have to be made for the aerial to move or "scan" the whole area that is to be searched. This may be a complete circle of 360 degrees or a comparatively narrow sector of it within which it is known that the object to be located is placed. The scan or rotation of the aerial is carried out mechanically. The aerial is turned round and round or backward and forward a definite number of times a second or perhaps only once in several seconds.

The need for scanning puts a severe limit on the practical size of the aerial. Recently, a method has been worked out by which scanning can be carried out electronically instead of mechanically: the aerial remains motionless but the beam moves rapidly. So far, it has been found possible to cover only a very narrow section in this way and it is not practicable for many of the purposes for which radar installations are used. But it is very useful where very accurate data on range and direction over a narrow sector are required, as in gun laying. In the case of anti-aircraft guns a method has been worked out whereby the aerial directs itself as it were; the beam is automatically kept pointing at the position from which the echoes are being received, so that the aerial "follows" the airplane without human guidance.

The pulses, having been generated and transmitted in the required direction, strike the "target" and, very much more feebly, are reflected. So far, there is no indication of value to the user of the radar set. To get information, he must pick up the echoed pulses and work out the time they have taken to cover

the double journey and he must also know from what poi in the transmitting aerial's "scan" the echoes are being receive

The transmitter is only half the radar set. The receiver i equally important. And it can be no simple receiver like th used for broadcast reception. Consider one point alone. Th receiver must be switched off every time the oscillator is pro ducing its powerful surges of energy; otherwise it would b burned out, and certainly it would be in no condition to recei the faint echoes. The receiver, therefore, is coupled to th transmitter in such a way that it is "dead" for the millionth o a second during which the pulse is being transmitted, but i back in action, ready to receive, a millionth of a second late when the echoes from the nearest objects might be expecte In radio language, the receiver must have a very "fast re sponse." It will be seen that the transmitting and receivin sides of the radar set are connected and work alternately, b the switching on and off has to occur hundreds of times second. No mechanical switch could work at anything ap proaching this speed and only electronic devices make it pos sible.

In most radar receivers the circuit is of the super-heterody type in which a radio frequency near that to be received i generated and beaten against the received signals to give a intermediate frequency which is amplified many times. In th case of radar there would be no purpose in listening to the sig nals, although they could be heard. They would be meaningles jumbles of sound. What is required is to measure the time th has elapsed since they were transmitted and the direction fro which they are being reflected. These two pieces of informatio will give the direction and distance of the object that has to b located. The direction from which the signals are being re ceived is given by the position of the aerial at the moment o reception. The time that has elapsed is measured electronical by connection between the transmitting and receiving sides o the set, and the accuracy is such that it is possible to determi the range of an object sending echoes to within a few yards a distance of several miles. Instead of using the mechanic position of the aerial as an indicator of direction, the streng of the received signals is used. As the beam "hits" the object

signals are strong, becoming weaker as the beam moves away, fading out altogether and then swelling to a peak again as the object is "scanned" once more.

To indicate this vital data, to obtain which is the whole purpose of a radar set, a cathode ray tube, sometimes more than one, is used. The beam of electrons in the tube is deflected in one plane for time and in another for direction and the results are displayed visually. There are a number of different ways in which radar data can be shown, each having its particular use. The simplest method is the "A-scope" in which a bright horizontal line across the "screen" of the cathode ray tube indicates time. If there are no echoes, the operator sees simply the horizontal line. If there is an echo it shows as a V or "pip" on this line and the distance along it indicates the time that has elapsed or, in other words, the distance.

This method of display is not altogether satisfactory for radars with aerials which scan in all directions and so a very ingenious device is used which, in fact, gives a "picture" of the surrounding object. The time base is a diameter of the circular cathode ray tube screen, but this rotates round the center of the aerial. When no object is located, nothing shows except a glow. When echoes are received, the glow at the particular point on the time base is intensified for an instant and the located object appears as a bright spot, correctly located in direction and distance from the center which is the aerial of the radar. Most radar aerials rotate comparatively slowly, taking anything from three to sixty seconds. This means that the object would be apparent on the screen only as a regular "flash" which would be inconvenient. The cathode ray tube, therefore, is treated with a chemical with persistent fluorescence, lasting for some time after the electrons have ceased to strike. The persistence is sufficiently long to give the illusion of a continuously glowing spot. The result is that, although the echoed signals are being received only at intervals, the bright spot on the cathode ray tube indicating distance and direction is continuous and can easily be watched. The effect of this method of indication, called Plan Position Indication or PPI, is to give a "map" of the surroundings of the radar set or, if it is used in an aircraft, of the ground underneath. Radar distinguishes very

clearly between water and land and therefore the PPI on an airplane indicates any coastline underneath. . . .

Radar is still not yet many years old. The possibilities of its peacetime application are only just being investigated. It is obviously one of the really important inventions of all time, for it provides us with a way of measuring distances or directions quite independently of the limitations imposed by our senses and of weather conditions. In this single chapter it is possible only to touch upon the principles of radar technique. Too great emphasis could hardly be given to the remarkable skill that has been called for in harnessing billions of electrons in so many ways. We have learned to deal with millionths of a second at literally lightning speed, not only making these complicated measurements with great accuracy in a small fraction of a second, but making them minute after minute, hour after hour, with a minimum of direct human control.

Chemistry's Secret Agents

American business firms, particularly those in manufacturing and technical fields, publish an incredible number of "house organs" aimed at customers, stockholders, or employees. Many would win no prizes for either literary or technical excellence, but many are very good. One of the best is *The Lamp*, published four times a year by the Standard Oil Company (New Jersey). Beside magnificent displays of photographs and drawings of far-flung oil industry activities, *The Lamp* frequently publishes illuminating articles on chemistry and other sciences related to petroleum. The article below, reprinted by permission of Standard Oil, is one of these. Its anonymous author (all articles in *The Lamp* are unsigned) has written a first-class popular account of catalysts, the mysterious agents that promote a number of the key chemical reactions on which today's huge chemical industry is based.

Did you ever try to burn a lump of sugar with a match? You can't. But place some cigarette ash on it, and you can. Nothing happens to the ash; it merely makes the chemical reaction of burning possible.

As sugar burns in the presence of ash, so a host of fundamental reactions take place in the presence of substances called catalysts. All chemical reactions involve changes in the reacting materials; the peculiarity of a catalytic reaction is that the catalyst which promotes it is not changed at all. In fact it emerges ready to play its catalytic role all over again.

Catalysts resemble, in a way, the "philosopher's stone," which ancient alchemists dreamed would transmute base metals into gold. Though catalysts cannot change one element into another, they do enable the modern chemist to create new materials by

breaking up or rearranging or combining the molecules of others.

Catalysts are somewhat mysterious agents, and it is only in recent years that the chemists have learned much about them. They remain mysterious to the layman because catalysis is not apparent in his everyday life.

For years industrial chemistry made use of many catalysts without completely understanding the nature of the reactions which took place. Today more than ten million tons of sulfuric acid are consumed annually in the United States by the metal and oil industries and by manufacturers of fertilizer, coal products, paint, synthetic fibers, and explosives. Most of this sulfuric acid is produced synthetically with the aid of a catalyst containing vanadium oxide.

A catalyst of granulated iron oxide keeps whole populations from starvation, because it makes possible the synthesis of cheap ammonia out of hydrogen and nitrogen. Ammonia by the hundreds of thousands of tons a year is converted into nitric acid and the life-giving nitrate-type fertilizers.

Most housewives have used hardened vegetable oils as substitutes for lard. This big food industry became possible only when a nickel powder (temporarily suspended in the oil) was developed as a catalyst which would cause solidification of the liquid when hydrogen gas was blown into it.

DDT, the best known of the new insecticides, is manufactured with the aid of an acid catalyst.

The petroleum industry is the largest user by far of industrial catalysts, and is the area in which the most spectacular recent advances in catalytic technique have been made. Catalysts put the manufacture of high octane gasoline on a mass production basis. Catalytic reactions perfected in the petroleum industry have pushed back the frontiers of knowledge and revealed new possibilities for the exploitation of natural materials and the creation of synthetic substances.

Petroleum was once refined simply by cooking it—applying varying degrees of heat and pressure. Heat and pressure are still used but catalysts, the petroleum chemist's new set of tools, have not only made possible entirely different refining operations but have given greater flexibility and higher efficiency to

the old ones.

Thermal cracking, in which the hydrocarbon molecules of petroleum are attacked with heat and pressure until they break down into smaller molecules, has already been supplanted to a great extent by catalytic cracking. Quantities of a synthetic or natural catalyst, composed largely of silica and alumina, crack the molecules much faster and direct the reaction so as to produce greater yields of higher quality products. The residue of low-grade and waste products is smaller. By altering the catalyst and the operating conditions, it can be made to yield many products in more nearly the proportions desired.

Catalytic cracking may be performed by passing the hot, vaporized feed stock (usually gas oil obtained by distilling crude petroleum) over a bed of lumps, pills, or beads of catalyst. In the continuous Fluid process of Standard Oil Development Company, the catalyst—a fine powder—is mixed with the feed stock before it enters the reaction chamber.

This catalyst, ordinarily sluggish like any powder, seems to take on a new property and to flow like water when aerated by gas or vapor. Thus a Fluid plant, though without a moving part, operates continuously for months on end, with catalyst constantly flowing out of the reaction chamber to a regenerator, to be cleansed of the carbon it accumulates, then returning along with fresh feed stock to the reactor.

The cracking catalysts can be prepared in the form of tiny particles called microspheres, relatively uniform in size, which may reduce erosion and dust collection problems.

Petroleum cracking catalysts are unique in that relatively huge quantities of them are required. In the catalytic hardening of vegetable oils (to take a typical case), the nickel catalyst is outweighed by the liquid vegetable oil a hundred or more to one. But in Fluid cracking the catalyst seething within the cylindrical reactor may at any given instant exceed the weight of the oil vapors by more than fifty times.

The gaseous hydrocarbons produced by catalytic cracking may participate in additional catalytic reactions which further add to, subtract from, or recombine their molecules.

An earth containing diatoms (remains of minute marine life) and impregnated with siruplike phosphoric acid is the

catalyst which converts several of these gases into hydrocarbons called polymers, used as blending stocks for high octane gasoline. Sulfuric acid (itself usually manufactured by catalysis) is employed as a catalyst to produce even higher grade blending stocks known as alkylates. A catalyst containing iron helps transform a refinery gas into an essential raw material of the Buna-type rubbers. Catalytic agents for still other reactions in the complex chemistry of petroleum are bauxite—a natural ore rich in aluminum oxide—and compounds containing the oxides of molybdenum, chromium, tungsten, zinc, magnesium, and many other metals.

An iron catalyst adapted to the revolutionary Fluid technique is the agent used in one of the steps by which natural gas or coal can be converted into liquid fuel and a long list of by-product chemicals. The latest of the major achievements of petroleum research, this application of the Fluid process makes hydrocarbon synthesis rank with catalytic cracking in the importance of its implications for the future.

Hydrocarbon synthesis was first performed in Germany, generally with expensive cobalt catalysts in a relatively inefficient fixed-bed type of operation. With the development of an inexpensive catalyst suitable for the Fluid technique, investment, maintenance, and operating costs have been reduced and the yield of high quality gasoline increased.

What mysterious force enables these catalysts—metals, clays, and acids in endless combinations—to set off sudden surges of chemical activity in substances apparently inert?

The force comes from the energy which all matter contains. Chemical reactions, catalytic or not, result from this ever present energy. Many substances, in theory, will react with each other, though perhaps so slowly that the reaction is imperceptible. Catalysts accelerate, in tremendous bursts, some of these gradual reactions.

Molecules have a tendency to cling, in a thin layer, to surfaces—a phenomenon termed adsorption. When adsorption occurs on the surface of the proper catalyst, the adsorbed molecules are stimulated into unusual activity by the molecules of the catalyst. When two or more kinds of reacting molecules are

present, they may be adsorbed simultaneously. Then, having been brought into abnormally close association, they interact and re-form into new combinations.

The total surface area of many catalysts is an important factor in their activity. One pound of Fluid cracking catalyst of the powdered or microspherical type, for example, has a surface area of twenty to a hundred acres. Though its structure is too fine to be seen clearly even under the electron microscope, a brush-heap arrangement of small clusters of its molecules is believed to account for this extraordinarily large surface.

Catalysts have occasionally been discovered by sheer accident. A classic example is the case of the chemist who, studying the reactions of naphthalene with sulfuric acid, accidentally broke the mercury thermometer with which he was stirring the mixture. The addition of mercury brought about a most unexpected result, and analysis showed that phthalic acid had been produced. Thus was discovered the catalytic action of mercuric sulfate.

Today, the search for a catalyst which will promote some desired reaction is usually simplified by prior knowledge of the class of agent to which the catalyst must belong. Beyond that point, the catalyst must be developed by trial and error. Experimentation is complicated by the fact that a substance which is not a catalyst may become one when a second substance, a "promoter," is added. And it may lose its catalytic activity in the presence of some third substance, a "poison."

Consider, for example, the search for a catalyst to promote the conversion of butylene to butadiene, for manufacture of the synthetic Buna rubbers.

This conversion had already been made successfully with the aid of a chromia catalyst. But the process on a huge commercial scale required massive equipment and possibly dangerous operating conditions. These problems would be overcome, it was believed, if steam could be introduced into the reaction chamber. Unfortunately, the chromia catalyst proved inactive in the presence of steam.

Standard Oil Development Company initiated an intensive program to develop a suitable catalyst which would not be inhibited by steam.

It was found that a chromia catalyst functioned, though not to complete satisfaction, when combined with magnesia as a base. Proceeding on the assumption that magnesia would be an ideal base for some catalyst as yet unknown, the researchers tried other substances in conjunction with magnesia. Iron oxide worked well but had a short life because it rapidly accumulated carbon. Potassium carbonate, added to the catalyst, reduced this accumulation. The catalyst was now fairly satisfactory but was slightly unstable, apparently as a result of the loss of some potassium carbonate in use. A fourth component, copper oxide, proved successful as a stabilizing agent.

The research at this point had required the energies of a group of four men, who prepared and tested more than a hundred catalyst compositions before one was obtained which was considered satisfactory. Early in 1942, with a rubber shortage imminent, plant designs were frozen on the basis of this catalyst, designated as Catalyst 1707. Though improvements on it have since been made, it was 1707 which successfully met this wartime emergency.

By such methods, though seldom with such early success, the chemists shape and refine their catalytic instruments for more precise performance of their will. Catalytic cracking has made available to them a series of chemical building blocks whose constructive potentialities are still being explored. Hydrocarbon synthesis promises to furnish even more of them. Alcohols of all types, scores of new resins and fibers, solvents, detergents, and soaps are already being synthesized from petroleum. The scientists themselves cannot predict what fresh shapes the versatile hydrocarbons may take when lashed into action by more efficient catalysts yet to be evolved.

C. W. BENDIGO

Man-Made Fibers

If someone were to ask a representative sample of the public to name the largest industry in the U.S., most people would unhesitatingly reply "steel." They would be wrong. Since World War II, the biggest industry in the U.S. has been the chemical industry, and it is getting bigger by the minute. The basic reason for its remarkable growth (it is doubling in size every ten to fifteen years) is the fantastic wealth of new products uncovered by chemical research, from new fertilizers to insecticides, from drugs to plastics and easy-to-apply do-it-yourself paints. This could as well be called the Chemical Age as the Age of Electricity or the Atomic Age. Among the most spectacular products of chemical research are the new synethetic fibers and textiles. The account of the new synthetic fibers below was especially written for this volume by an expert on the syhthetics, C. W. Bendigo, manager of the Fiber Market Development Department, American Cyanamid Company.

A traveler steps out of a railway station into a summer rain. He walks several blocks to his hotel room, carrying only a small case containing toothbrush and shaving gear.

In his room he undresses, hangs up his drenched and crumpled suit, rinses out his underwear, shirt and socks, and hangs them up to dry. The next morning his shirt is clean and crisp, with a freshly ironed look. His suit, dry long before he awakened, has lost its wrinkles and "bagginess." Only the sharp creases that belong remain. When he leaves his hotel, he looks as if he were wearing a fresh change of clothes.

He can live this way for weeks. He need carry no baggage, see no tailor, wait for no laundry.

He owes his freedom to man-made fibers. During the last

several years, man-made fibers have aroused interest everywhere. Textiles made from natural fibers still outsell synthetics at least fifty to one. Everyone is talking about man-made fibers nevertheless.

The reason is not hard to find. For centuries, there have been only four principal fibers available: cotton, wool, flax, and silk. These—each with its good and bad points—are not enough to cope with the thousands of different jobs that fibers are called upon to perform today.

To do all the tasks now expected of textile materials, fibers with completely new properties are needed. Since they are not to be found in nature, man must look to his scientific resources for them. To an increasing extent that is where they are being found—in the laboratory.

When the search for synthetic fibers began, there was some talk of looking for a "universal fiber"—a fiber that would be good for all purposes. It has not been found and probably never will be, for it would have to embody mutually exclusive features. It would have to be at once rugged and delicate, absorbent and non-absorbent, cool and warm, rough and smooth, flexible and inflexible.

These "opposites" would not be wanted in the same garments or textiles. For some, such as shirts, dimensional stability is needed so that garments cut to size will neither shrink nor grow. For other articles of clothing, such as hosiery, elasticity is essential. Some elasticity can be obtained by knitting instead of weaving, but part must come from elasticity inherent in the fiber, certainly when the ultimate is wanted.

For some fabrics, great strength and abrasion resistance are required in order to obtain sheerness, as in blouses. In others, such as in most wool fabrics, fiber strength is not important, and wear is obtained from the thickness of the fabric. If wool were made into sheer fabrics, its useful life would be disappointing to say the least. Its wear and strength are satisfactory only because wool fabrics are made comparatively heavy. Cotton fabrics the same thickness as wool would wear several times as long—but the cotton would mat down into a hard mass, while wool does not. For some uses fibers must be soft, as in sweaters, for others, comparatively stiff, as in blankets.

The modern textile scientist offers something much better than the "universal fiber." He is providing fibers that can be made into fabrics tailored to specific jobs. In practice, he is not looking for fibers that will do only a single job; any fiber developed today is measured against some fifty properties it must have to make it worthwhile as a textile material. But the range of properties is sufficiently great that fabrics with nearly any desired specific properties are possible.

A convenient starting point for seeing what textile scientists have accomplished is a look at the textile field as a whole. All textile fibers, whether man-made or natural, fall into two classes. They are either continuous filaments or staple. Continuous filaments are just what the name implies. Staple consists of short fibers which must be combed out (to make the fibers lie parallel to each other) and twisted or spun to form yarn. Before being processed into yarn, staple looks very much like common absorbent cotton.

Natural fibers come only as nature supplies them. Silk is a continuous filament yarn—the only natural one of textile importance. Cotton and wool are staple fibers. Cotton fibers are around an inch long; wool fibers range up to several inches in length.

Man-made fibers, on the other hand, are always produced in continuous lengths. However, they may be cut to staple length if desired. The lengths usually used are 1½ inches for staple to be processed on cotton equipment, 2 inches for staple to be processed on spun rayon (modified cotton) equipment, 2 to 3½ inches for staple to be processed on woolen equipment, and from 3 to 4½ inches for staple to be processed on machinery of the type previously used for handling worsted yarns (yarns made from the longest wool fibers).

The reason for the two forms of fiber, filament and staple, is to permit different types of fabrics to be produced. Historically, filament synthetics followed the pattern laid down by silk. Filament yarns are used for women's hosiery, women's underwear, "silk" socks, "silk" dresses, better-quality linings. Synthetic staple fibers are produced in order to make fabrics resembling cotton and wool textiles. Fabrics made from staple are always fuzzy and are usually heavier than those made from filament.

They are generally used for purposes for which filament-yarn fabrics are unsuited, such as most men's suitings, winter-weight dresses, coats, and blankets.

The commercial history of truly synthetic fibers begins in 1938 with the advent of nylon. Rayon and acetate came earlier, but they are not true synthetics. Chemically, they consist of cellulose, the same substance cotton is composed of, and are made by dissolving cellulose-containing materials (like cotton linters or wood chips) and forming the cellulose into new fibers. Properly speaking, rayon and acetate are "regenerated cellulose" fibers.

Dr. Wallace H. Carothers and a team of chemists in the laboratories of the Du Pont company are credited with the groundwork which made possible the development of nylon. Dr. Carothers studied the composition and behavior of the very large molecules found in such things as rubber, plastics, and natural fibers. He made the simple but profound observation that, since fibers are so very much longer than they are thick, perhaps the molecules of which they are composed have the same general shape. He set out to find the various types of small molecules that could be made to react with themselves or with other small molecules to form long, chain-like molecules. He found two general types. One would add to itself to form "addition polymers." Another required a special type of chemical condensation reaction, so these are called "condensation polymers." Nylon is the best example of condensation fiber, and Orlon acrylic fiber of an addition type.

Chemists and chemical engineers have literally worked wonders in developing commercial processes for producing polymers, then spinning the polymers into filaments most of which are finer than human hair. Polymerization (as the process of forming polymers is called) must be carried out under extremely precise control because the polymer molecules must be quite uniform in length. If many of the molecules are too short, the fiber will lack strength; if many are too long, the fiber will be difficult to spin into suitable yarn.

Polymers for the production of fibers have been made from a variety of substances. At the present time, no less than eight distinct types of synthetic fibers are being made. These include

nylon; two fibers made from an acrylic plastic (Acrilan and Orlon); a fiber based partly on acrylic resin (Dynel); Dacron, a fiber based on a polyester plastic; fibers based on polyethylene (the plastic made famous by "squeeze" bottles); two fibers based on rather different derivatives of the gas acetylene (Saran and Vinyon); and a fiber based on Teflon, a plastic-like material used largely for industrial purposes.

Nylon is produced in by far the largest quantity. In 1954, 280 million pounds were used (ninety per cent of it in filament yarn). Next in order of volume are the acrylics, and then come the polyesters. Over three-quarters of the acrylics and polyesters were produced as staple for spinning and weaving into cloth.

The synthetic fibers produced in the United States have excellent dimensional stability. They neither shrink nor stretch more than two per cent. This does not apply to some foreign synthetics. The reason for this is largely that American synthetics are hydrophobic; they repel water instead of absorbing it, and hence do not swell and get out of shape. This same property is responsible for their ability to retain creases and pleats, and for their excellent performance in damp weather, and also for their ability to dry quickly after laundering.

All hydrophobic fibers, however, do not behave in the same way when in contact with water. Some, like the acrylics, pass moisture between the fibers even though very little goes into the fibers themselves. Others, particularly nylon, neither absorb nor pass moisture well and thus may feel clammy or even sticky.

One respect in which all present synthetics are excellent is lack of flammability. Nylon, Dacron, and Dynel do not support combustion. None of the others burns well enough to be dangerous; none will flash burn, as does untreated cotton or rayon. For practical purposes, moreover, combustion fumes are no more toxic than those generated by burning wool. But the synthetics will melt if heated to a high enough temperature.

Like natural fibers, the synthetics vary substantially in their properties. For example, nylon is outstanding for wear and strength. For a combination of wrinkle resistance and wear, fabrics from Dacron polyester fiber are excellent. For warmth, fabrics made from acrylic fibers top all others, natural or syn-

thetic. And Orlon acrylic fiber has unusual resistance to weathering. On the other hand, none of the synthetic fibers has the loft (ability to spring back after being pressed down) of wool. Moreover, the synthetics are expensive, and they are more difficult to dye, which is understandable since dyes for cotton and wool have been developed over centuries, whereas dyes for the synthetics have been under development for a few years only.

One of the best ways to utilize the synthetic fibers, as well as natural fibers, is to blend or mix them. In that way, one can combine the advantages of different yarns, and, to a surprising degree, avoid some of the disadvantages which any single fiber inevitably possesses. For example, there is no textile woven from a synthetic staple fiber whose loft cannot be improved by the addition of wool. Conversely, the wear of a wool fabric can be greatly increased by the addition of nylon. In fact blends are rapidly coming to dominate several areas of the textile field. Of course there are some areas where blends are unfeasible or undesirable. Thus, only one yarn can usually be used in extremely fine fabrics, as in women's lingerie; and women's hosiery would not be improved by blending other yarns with nylon filament (if indeed that were technically possible; the blending of filament yarns is much more difficult than the blending of staple). But for many purposes, blends promise—and are already delivering—clothing with combinations of properties that have never been possible before.

The advent of the blends, though, does pose something of a problem for the consumer. In the old days, one could tell something about an article of clothing by looking at the label: "pure wool" and so on was a simple designation that told a great deal (though not everything, because the quality of a garment also depends on how well it is styled and made). "Forty per cent Acrilan, forty per cent wool," however, means much less to the consumer; and as more complex blends come on the market, labels reporting fiber content are going to mean still less. The consumer will probably have to learn to depend on the clothing manufacturer's brand name and reputation for quality of the fabric, as well as the style and manufacture of a garment. The only alternative is for the consumer to become an expert in every fiber.

Now, what of the future? As I see it, at least three exciting developments are coming.

One is the development of soft, springy fabrics of 100 per cent synthetic fiber. In the textile trade, the development is called "high bulk" and is the basis of Orlon and Acrilan sweaters. High-bulk fibers are made by blending shrinkable and shrink-proof fibers; when the blended fibers are treated with hot water, the shrinkable fibers cause the shrink-proof ones to buckle and assume a bulky shape.

Another is the development of wholly new classes of fabrics. In the past, there has been a clear line of demarcation between articles made from staple (woven goods, generally) and from filament (articles like stockings). Several recent advances are breaking down this distinction. One is the manufacture of fleece fabrics from Orlon filament, such as baby blankets. Orlon filament fleece (made from specially constructed fabrics that are brushed up into a pile) more nearly performs like wool or fur than any other fiber yet made by man.

Another advance that is breaking down traditional distinctions between filament and staple fabrics is nylon "stretch" yarn. This yarn (elasticized by any one of several special processes) is already sweeping the hosiery field, providing "stretch" socks and stockings that fit better than any hosiery material ever available before. Still another development is "texturized filament." Texturized filaments contain millions of tiny loops. With texturized filament yarns it will be possible to make fabrics that are neither like conventional knit or woven goods, but will provide a new range of attractive effects somewhere in between.

The third important prospect for the future is the application of some of the treatment techniques learned with synthetic fibers to improve the natural fibers. Until a comparatively few years ago, man was content to leave cotton, wool, and other natural fibers very much as nature provided them. Actually, there is no reason why he should not try to improve them. They have many wonderful properties to begin with, and they are less expensive than fibers that man must make from scratch. Much has already been done, and more will be done. I will mention here only one recently announced development, the cyanoethylation of cotton. This process has turned cotton, with-

out loss of any of its desirable properties, into a fiber highly resistant to acids, heat, and electricity and virtually rot-proof. Every few months now sees the announcement of other new methods of improving the properties of natural fibers.

It is no exaggeration to say that the revolution effected by the application of chemical science to textiles has only begun. We can confidently look forward to a range of textile materials, both man-made and natural fibers modified by man, such as we have never possessed before.

CHARLES E. O'HARA and
JAMES W. OSTERBURG

Incriminating Stains

Ordinarily when one thinks of applications of physics and chemistry one thinks of atomic power, engineering, industry, medicine, and the like. But the use of chemistry and physics to apprehend criminals is a legitimate, useful, and extremely interesting application of science, too, as Messrs. O'Hara and Osterburg demonstrate in their article. "Incriminating Stains" is reprinted from the February, 1953, Vol. 188, No. 2, issue of *Scientific American*, by permission of the magazine. Messrs. O'Hara and Osterburg are authors of a standard textbook in police work, *An Introduction to Criminalistics*.

Mystery story writers have always been partial to evidence in the form of stains or spots. The goat blood *qua* human blood on Joseph's coat (which would not have fooled a modern police laboratory for long) is perhaps the earliest recorded instance of this type of clue. Sherlock Holmes was seldom so impressive as when deducing a client's occupation, habits, and recent whereabouts from the assorted spots and debris on his person and the color of the mud on his boots. The ingenuity and lightning speed of Holmes's inferences set a style for the mystery novel.

Within the last fifteen years the fictional sleuth has given up curbstone chemistry and permitted his gleanings to be sent to a laboratory. From a literary viewpoint this is a step backward. Yet it is an inevitable and realistic recognition of the facts of life. In modern crime detection the man in the armchair has yielded to the man in the white gown.

Joseph's coat and Holmes's boots illustrate the two major

questions which the police ask about a stain: (1) What is it? (2) Where did it come from, and can it be connected with a suspect? The latter is a classic problem of criminalistics, and the successful association of an incriminating material with a suspect constitutes scientific evidence *par excellence*—often preferable to casual eyewitness testimony.

Some spots—narcotics, chloral hydrate (knockout drops), poisons—may themselves constitute the *corpus delicti*. Sometimes stains provide a running story of the crime. For example, recently the police were able to reconstruct how a killing had taken place by examining an apartment generously splashed with the blood of the killer and of his two victims. Again, identification of a telltale stain such as printer's ink or confectioner's sugar may lead to the criminal. And of course there is the conclusive evidence of a spot on a suspect that may be linked to a substance at the scene of a crime: a white smudge on the shoes of a burglary suspect, for instance, may be identified as insulating material from a particular broken safe.

These, in brief, are the kinds of stories stains may tell. The finding and analysis of stains or spots are, however, complicated problems.

The first step in attempting to solve a crime by the stains left behind is to search likely places for spots or smears. The garments of the victim or suspect are commonly the first objects inspected. If the crime is one of violence, the police look for excretory fluids: blood, sweat, saliva, and semen are frequently emitted during a criminal struggle. These fluids can usually be classified: blood can always be, if the stain is reasonably large and fresh, and the other three fluids can be for about eighty per cent of the population.

Of the four, blood is by far the most important to police work. It possesses three of the qualities of a good identification medium: everyone has it in generous quantities, it is often left at the scene of a crime, and it has specific characteristics. A crime laboratory performs tests to answer this series of questions: Is it blood? Is it human blood? What is its type?

Even a dried bloodstain, if it is large enough (the size of a half-dollar) and not too old, can usually be identified according to its major group: O, A, B, or AB. Fresh blood can be classified

much more specifically; considering its Rh type and other identifying characteristics it may be placed in one of many thousands of subdivisions.

Bloodstains on the person or clothing are less useful for discovering a suspect than most laymen and many policemen suppose. A prolonged scrutiny of almost anyone's clothes may reveal minute specks of blood. The fingernails are a favorite area of exploration for enthusiastic district attorneys, but blood found there usually has a discouragingly innocent explanation; it is a common result of manual labor or routine hygienic performances. More often than not such "invisible" bloodstains put investigators on a false track.

Once a lead has been established, however, blood can provide important corroborating evidence. By the same token, it is often valuable in clearing the guiltless; the vindication of innocence has historically been an important function of blood examination. Many a lynching might have been prevented simply by a bood test. For instance, not long ago a farmer's wife was found murdered in the South, and a Negro picked up in the neighborhood was found to have blood on the sleeve of his jacket. He attributed it to a recent hunting expedition. After a mob had lynched him, an examination of his jacket proved that the stain was animal blood. Eventually it was found that the woman had been killed by her husband.

Semen is the second most important serological stain. As a corroboratory evidence of rape or sodomy, it is looked for on garments of the victim. The police scientist first examines the garment under untraviolet light, because semen is fluorescent. If he finds fluorescent spots, he dissolves some of the stain and examines the extract under a microscope; the presence of spermatozoa will then identify it as semen.

Serological stains are seldom of more than routine interest to the crime laboratory. More challenging are the stains of other types, which are not only more common but usually more difficult to identify and trace.

For example, motor-vehicle homicides (usually hit-and-run cases) number about thirty thousand a year and are a far greater problem to the police of a large city than the few hundred murders that make the headlines. In a typical hit-and-run

case bits of paint from the missing car may be found on the buttons or belt of the victim. As soon as a car is picked up on suspicion, the men working on the case will send a sample of its paint to the laboratory for comparison by spectroscope. While in most paints the main ingredients are the same, a specific batch of paint may be identified by its content of trace elements, or impurities. Here the police scientist resorts to the theory of probability. If, to take an over-simplified case, we assume that the probability of finding a specific impurity in a given batch of paint is one in ten, and if we find ten such impurities, the probability that just this combination of impurities will be found in any other batch of paint is only one chance in ten billion. Obviously such a coincidence is far beyond the leeway provided by reasonable doubt; the chances of finding two identical batches of paint of this composition are even smaller than of finding two human fingerprints exactly alike. In practice the situation is not usually so clear-cut. Some elements are more common than others, some tend to run in groups. The probability calculation is often exceedingly complex, and part of the technician's job is to phrase the results in accurate terms that are comprehensible in the courtroom.

Police work has been enormously helped by the spectrograph and other rapid instruments of chemical and physical analysis. They can deal with minute samples, which are frequently all that the case affords, and they can reveal physical or chemical characteristics so great in number, so diverse in nature or so rare in occurrence as to preclude all but a negligible probability of duplication by coincidence. They permit analysis without disturbing the sample, thus making it possible to keep the evidence intact for presentation in court and for tests by the defense. Moreover, with these instruments a police technician does not have to be an expert in every branch of chemical analysis. A reasonable familiarity with the techniques, the basic materials, the fillers, and the accidental trace elements of the industries from which his samples come is enough for effective use of his instruments.

The instruments serve first of all to locate the clues. Just as fluorescence will call attention to semen stains, X-rays will disclose gunpowder marks. When a gun is discharged at short

range, a halo of smoke is deposited on the target. On dark cloth this effect is hard to see, but soft X-rays show the lead fouling and give some indication of the distance from which the weapon was fired. Infrared radiation is useful for distinguishing stains which otherwise look alike. It is even more valuable for exposing something that has been blotted out. Thus on a blood-stained document the writing under the stain can often be restored to legibility by an infrared photograph. Inks vary in their opacity to infrared rays, and a message that has been scored out can sometimes be deciphered by this method if the two inks are of different composition.

The spectrophotometer also has proved its worth in crime detection. It can detect tiny differences in inks, dyes, lipsticks, and some other materials. Moreover, it provides evidence in precise, objective mathematical terms and is especially valuable in court. The spectrophotometer was used effectively in a recent mugging case. A woman walking home from the subway was gripped from behind by an assailant who clapped his hand over her mouth, grabbed her handbag, and ran. She screamed for help. A few minutes later a man was picked up by the police three blocks from the scene. The woman had not seen the thief's face, and there was no evidence to link the suspect to the crime except his proximity, his suspicious behavior, and a red smear on the palm of his left hand. But a spectrophotometric analysis showed that the substance on his hand had the same absorption spectrum as the woman's lipstick. This, with supporting evidence, was sufficient to convict him.

When a stain can be made to yield crystals, or at least a substance which is not truly amorphous, it may be analyzed by X-ray diffraction. An X-ray diffraction camera can distinguish substances identical in chemical constituency but differing in atomic arrangement. Not long ago a man was found dead on the ground beneath the window of his garret room. It was supposed that he had committed suicide. But on the low, slanting ceiling near the window were some black smudges. An X-ray diffraction picture showed that the material was the same as in the heels of the deceased's shoes. The smudges could hardly have been made on the ceiling if he had jumped; he must have been picked up and pushed out. After further investigation

two casual acquaintances of the man were arrested, and they admitted they had been with him.

X-ray diffraction is used to identify and compare barbiturates, which are ordinarily distinguishable only by their melting points. Grease stains also can be recognized by this device. In one case the prosecution claimed that the stain on a defendant's clothing was kitchen grease from the scene of the crime. The defense maintained that it was auto grease. X-ray diffraction analysis of the sample, less than a milligram, proved that the stain was kitchen grease.

The electron microscope promises to yield valuable information from such clue materials as dust, metals, fibers, inks, and other materials whose particle size and distribution cannot be differentiated by less sensitive instruments. It was used effectively two years ago in connection with the murder of a woman by a burglar. A suspect was "developed," but the police could discover no stolen property in his possession, nor could they trace his activities on the night in question. They did, however, find in his room a towel bearing a pink stain. The laboratory determined that this small stain was face powder, and under the electron microscope it was identified with powder in the woman's compact. Faced with this evidence, the suspect confessed to the crime.

Often the police can assure that a thief will pick up an incriminating stain at the scene of the crime. Where there has been a systematic series of petty thefts, they may plant a "detective dye," such as rhodamine B or eosine, which is hard to wash off. Rhodamine B may be brushed on a brown wallet, or a green dye on greenbacks. For a thief this is "non-protective coloration." When he touches the wallet or the bills, perspiration dissolves the dye and leaves a brilliant stain on his hand. Surveillance of nearby washrooms often catches the thief. When a continuous vigil is impracticable, a small quantity of fluorescent powder can be sprinkled on the object. The powder will be spread on the hands and clothing of the unsuspecting thief, and subsequent examination under ultraviolet light will expose him. Blackmail-letter writers have been caught with a fluorescent powder dissolved in their ink supply.

The labeling technique should have a big future in crime

detection, now that we have radioactive isotopes to add to the other labeling substances. Fingerprints have always been an ideal means of placing a criminal at the scene of the crime, but unfortunately criminals know that as well as the police. Already it has become the practice to tag some materials that figure frequently in crimes with radioisotopes, fluorescent substances, or rare elements. Radioactive substances have been employed to label "company" gasoline and prevent pilfering. Pari-mutuel tickets are sometimes impregnated with a fluorescent dye for identification; the cashier looks at them under an ultraviolet lamp to make sure they are genuine. During the last war ration coupons were similarly treated to detect forgeries.

To extend this method of attack on crime would require the co-operation of the manufacturers of common clue materials. Two outstanding examples are bullets and lipsticks. Trace elements placed in a bullet or lipstick could tell us three things: the name of the maker, the area of distribution, and the year of manufacture. That knowledge would go a long way toward making it easier to solve crimes involving guns or women. So far manufacturers have rejected the suggestion, arguing that labeling could only rarely be useful to the police and it would not contribute to the commercial success of their products. Some manufacturers of wire do label their product with tracers, but primarily to prevent mislabeling and protect their own reputations. Most of the manufacturers of cosmetics have even refused to tell the police confidentially the ingredients of their lipsticks, on the ground of protecting themselves from imitation. On investigation it was discovered that those who refused were for the most part selling lipsticks obtained from "super-wholesalers"; many employ the same source and in fact the same lipstick, but give it their own name and their own highly individual claims.

These failures do not dismay the scientific criminologist. He has been similarly blocked in other utopian projects. Nor would he seek to compel manufacturers to co-operate, since compulsion would negate his function, which is to guarantee in his own small way the people's freedom in the lawful pursuit of their ways of life.

4. Life

A. I. OPARIN

The Origin of Life

In recent years, there has been a revival of interest in an old question, the origin of life. A current theory is that living matter originated through the combination of amino acids and other compounds into something resembling simple viruses. Under conditions thought to have obtained on earth a billion years or so ago—when life is believed to have appeared—it is possible that amino acids could have been built up from elementary substances by natural processes. Indeed, early in 1953, Stanley L. Miller of the University of Chicago succeeded in producing amino acids in the laboratory under presumed primitive earth conditions.

The source of the current speculation on the beginning of life is a short book, *The Origin of Life*, written by a Russian scientist, A. I. Oparin, during the 1930's. The concluding chapter of Oparin's fascinating book is reprinted below by permission of Dr. Sergius Morgulis of the University of Nebraska, who translated the volume, and of Dover Publications, Inc., New York 10, New York. *The Origin of Life* is one of the volumes in Dover's excellent series of inexpensive paperback reprints of scientific classics.

Summarizing what has been discussed in the preceding chapters, one must first of all categorically reject every attempt to renew the old arguments in favor of a sudden and spontaneous generation of life. It must be understood that no matter how

minute an organism may be or how elementary it may appear at first glance it is nevertheless infinitely more complex than any simple solution of organic substances. It possesses a definite dynamically stable structural organization which is founded upon a harmonious combination of strictly co-ordinated chemical reactions. It would be senseless to expect that such an organization could originate accidentally in a more or less brief span of time from simple solutions or infusions.

However, this need not lead us to the conclusion that there is an absolute and fundamental difference between a living organism and lifeless matter. Everyday experience enables one to differentiate living things from their non-living environment. But the numerous attempts to discover some specific "vital energies" resident only in organisms invariably ended in total failure, as the history of biology in the nineteenth and twentieth centuries teaches us.

That being the case, life could not have existed always. The complex combination of manifestations and properties so characteristic of life must have arisen in the process of evolution of matter. A weak attempt has been made in these pages to draw a picture of this evolution without losing contact with the ground of scientifically established facts.

The gaseous mass which had once separated from the sun, owing to a cosmic catastrophe, furnished the material out of which our planet was formed. Carbon together with other elements of the solar atmosphere passed into this gaseous mass which ultimately was destined to form our earth. Carbon is distinguished among all the chemical elements by its exceptional ability to form atomic associations, and is found invariably in all living things. Even at temperatures similar to those prevailing on the sun's surface its atoms are united in pairs, and on further cooling it tends to form molecules with even greater numbers of atoms. Therefore, in the process of formation of our planet from the original incandescent mass of gas, heavy clouds of carbon must have very quickly condensed into drops or even solid particles and entered the primitive nucleus of the earth in the form of a carbonaceous rain or snow. There the carbon came into immediate contact with the elements of heavy metals forming the nucleus, primarily with iron which constitutes such

an essential component of the central core of our present earth.

Mixed with the heavy metals, the carbon reacted chemically as the earth gradually cooled off, whereby carbides were produced, which are the carbon compounds most stable at high temperatures. The crust of primary igneous rocks which were formed subsequently separated the carbides from the earth's atmosphere. The atmosphere at that period differed materially from our present atmosphere in that it contained neither oxygen nor nitrogen gas but was filled instead with superheated aqueous vapor. The crust separating the carbides from this atmosphere still lacked rigidity to resist the gigantic tides of the inner molten liquid mass, caused by the attractive forces of sun and moon. The thin layer of igneous rock would rupture during these tides and through the crevices so formed the molten liquid mass from the interior depths would spread over the earth's surface. The superheated aqueous vapor of the atmosphere coming in contact with the carbides reacted chemically giving rise to the simplest organic matter, the hydrocarbons, which in turn gave rise to a great variety of derivatives (alcohols, aldehydes, ketones, organic acids, etc.) through oxidation by the oxygen component of water. At the same time these hydrocarbons also reacted with ammonia which appeared at that period on the surface of the earth. Thus amides, amines and other nitrogenous derivatives originated.

Thus it came about, when our planet had cooled off sufficiently to allow the condensation of aqueous vapor and the formation of the first envelope of hot water around the earth, that this water already contained in solution organic substances, the molecules of which were made up of carbon, hydrogen, oxygen, and nitrogen. These organic substances are endowed with tremendous chemical potentialities, and they entered a variety of chemical reactions not only with each other but also with the elements of the water itself. As a consequence of these reactions complex, high-molecular organic compounds were produced similar to those which at the present time compose the organism of animals and plants. By this process also the biologically most important compounds, the proteins, must have originated.

At first these substances were present in the waters of seas

and oceans in the form of colloidal solutions. Their molecules were dispersed and uniformly distributed in the solvent, but entirely inseparable from the dispersing medium. But as the colloidal solutions of various substances were mixed new and special formations resulted, the so-called coazervates or semi-liquid colloidal gels. In this process organic substance becomes concentrated in definite spatial arrangements and separated from the solvent medium by a more or less distinct membrane. Inside these coazervates or gels the colloidal particles assume a definite position toward each other; in other words, the beginnings of some elementary structure appear in them. Each coazervate droplet acquires a certain degree of individuality and its further fate is now determined not only by the conditions of the external medium but also by its own specific internal physico-chemical structure. This internal structure of the droplet determined its ability to absorb with greater or less speed and to incorporate into itself organic substances dissolved in the surrounding water. This resulted in an increase of the size of the droplet, i.e., they acquired the power to grow. But the rate of growth depends upon the internal physico-chemical structure of a given colloidal system and is greater the more this is adapted for absorption and for the chemical transformation of the absorbed materials.

In such manner a peculiar situation had arisen which may be described as the growth competition of coazervate gels. However, the physico-chemical structure of gels during growth did not remain unaltered but tended constantly to change owing to the addition of new substances, to chemical interaction, etc. These transformations could either result in a further perfection of the organization or, on the contrary, induce degradation and loss of structure. In other words, the process could bring about self-destruction and resolution of the coazervate droplet which was itself responsible for starting it. Only such changes in the structure of colloidal systems which enabled the gel to absorb dissolved substances more rapidly and thus to grow better, in other words only changes of a progressive kind, acquired importance for continued existence and development. A peculiar selective process had thus come into play which finally resulted in the origin of colloidal systems with a highly developed

physico-chemical organization, namely, the simplest primary organisms.

This brief survey purports to show the gradual evolution of organic substances and the manner by which ever newer properties, subject to laws of a higher order, were superimposed step by step upon the erstwhile simple and elementary properties of matter. At first there were the simple solutions of organic substances, whose behavior was governed by the properties of their component atoms and the arrangement of those atoms in the molecular structure. But gradually as a result of growth and increased complexity of the molecules, new properties have come into being and a new colloid-chemical order was imposed upon the more simple organic chemical relations. These newer properties were determined by the spatial arrangement and mutual relationship of the molecules. Even this configuration of organic matter was still insufficient to give rise to primary living things. For this, the colloidal systems in the process of their evolution had to acquire properties of a still higher order, which would permit the attainment of the next and more advanced phase in the organization of matter. In this process biological orderliness already comes into prominence. Competitive speed of growth, struggle for existence and, finally, natural selection determined such a form of material organization which is characteristic of living things of the present time.

Natural selection has long ago destroyed and completely wiped off the face of the earth all the intermediate forms of organization of primary colloidal systems and of the simplest living things and, wherever the external conditions are favorable to the evolution of life, we find countless numbers of fully developed highly organized living things. If organic matter would appear at the present time it could not evolve for very long because it would be quickly consumed and destroyed by the innumerable microörganisms inhabiting the earth, water, and air. For this reason, the process of evolution of organic substance, the process of formation of life sketched in the preceding pages cannot be observed directly now. The tremendously long intervals of time separating the single steps in this process make it impossible to reproduce the process as it occurred in nature under available laboratory conditions.

There still remains, however, the problem of the artificial synthesis of organisms; but for its solution a very detailed knowledge of the most intimate, internal structure of living things is essential. Even the synthesis of comparatively simple organic combinations can be accomplished only when one possesses a more or less complete understanding of the atomic arrangement of their molecules. This, of course, would apply even more so in the case of such complex systems as organisms. We are still too far removed from such a comprehensive knowledge of the living organism to even dream of attempting their chemical synthesis. For the present research into the origin of life must, therefore, be restricted to studies of a purely analytical character.

We are faced with a colossal problem of investigating each separate stage of the evolutionary process as it was sketched here. We must delve into the properties of proteins, we must learn the structure of colloidal organic systems, of enzymes, of protoplasmic organization, etc. The road ahead is hard and long but without doubt it leads to the ultimate knowledge of the nature of life. The artificial building or synthesis of living things is a very remote, but not an unattainable, goal along the road.

F. MACFARLANE BURNET

The Physical Nature of Viruses

Man and other large creatures dwell amid a microbial underworld of which we were really unaware until Pasteur connected microbes with disease. The smallest inhabitants of this world are described in "The Physical Nature of Viruses." The latter is included by permission of Penguin Books Limited, from *Viruses and Man* by F. M. Burnet, one of the excellent Penguin and Pelican paperback books published in England and available in too few stores in the United States. Dr. Burnet, an Australian, is the world's foremost authority on viruses.

At the time *Viruses and Man* was written, electron microscope photographs of the polio virus had, as Dr. Burnet states, not been made. However, two U. S. laboratories successfully made them in 1955.

From the earliest days of bacteriology there has been a peculiar fascination in the contrast between the smallness of microörganisms and the severity of the diseases they produce. With the discovery of viruses the contrast became even more striking. Here were agents of disease so much smaller than bacteria that they were beyond the range of the best available microscopes. The situation presented a challenge to the microscopist to produce an instrument that could escape the physical limitations of the ordinary microscope and allow viruses to be "seen" somehow or other. The physicist could say at once that the only way of doing this was to use some finer form of radiation than light to produce the desired image.

Around 1925 a successful microscope using ultraviolet light of shorter wave length than ordinary light was developed, and pictures of some of the larger viruses were obtained. Once the

physicists had reached an understanding of the properties of electrons regarded as packets of electromagnetic waves, it was obvious that theoretically at least electron beams could be used to give enlarged images of the objects far below the minimal size needed for resolution with a light microscope. In 1938 Von Borries and Ruzka published in Berlin the first pictures of viruses taken by an electron miscroscope. In the intervening period a large number of viruses have been depicted in the electron micrographs and to most people these pictures are liable to represent the highlights of virus research.

I am something of a heretic in believing that what viruses *do* and how they do it is very much more important than what they *are*. In recent years we have found out much about the physical and chemical nature of the more easily handled viruses and with the electron miscroscope we have obtained some beautiful pictures. In some ways this work on the purification and characterization of plant and animal viruses has been one of the great achievements of this scientific generation. It required the use of the most advanced physical and chemical techniques and great ingenuity in devising ways of concentrating milligrams of virus from kilograms of infected tissues. Dr. W. M. Stanley received a Nobel prize for his success in such work with tobacco mosaic virus and influenza virus. This was work in the very best traditions of modern biochemistry—and yet there is more than a suspicion that it has not got us very far.

Medical research is based and must be based on two premises: (1) that its objective is to satisfy the universal human desire for health and the prolongation of life, that its function is to strive constantly for the prevention and cure of disease, and (2) that in doing so it must apply to the problems of health and disease all the logical and technical processes that make up the scientific method. Both are equally important, but the first must come first.

From the human point of view the important things about viruses are their virulence, their restriction to certain cells and tissues of their hosts, how they multiply in and damage the cells they infect, their variations and the way in which they provoke immunity of varying strength in the people who have recovered from an attack. So far nothing that has been dis-

covered about the physical and chemical nature of viruses has thrown significant light on any of these characteristics. There are signs that in time we may build upon and elaborate present knowledge of what viruses are to such a point as will make that knowledge of high practical consequence, but to me this seems a long way off. However exciting it may seem to produce clear electron micrographs of influenza virus or to analyze milligrams of the virus particles into their chemical constituents, these are advances that have no immediate bearing on any of the practical problems of influenza.

There is to me a rather curious similarity between the work which has given us the sizes and shapes of viruses and those other studies which have worked out the distances, sizes, and compositions of the stars. Neither has any bearing on everyday life, both offer tribute to the curiosity and ingenuity of men, and both have enormous and sinister implications for the future. The two absolute weapons for the extermination of our species are (1) the type of bomb which will utilize the atomic reactions which give rise to the supernovae, and (2) the virus which will produce a lethal epidemic amongst the enemy but can be rendered harmless to one's friends by their appropriate immunization. When we understand the structure of viruses as well as we do that of the stars we shall doubtless be hard at work constructing the biological analogue of the hydrogen bomb.

The discovery of the basic fact that viruses were "filterable" afforded a strong presumption that they were smaller than the bacteria which were held back by the filters used. Provided the particles concerned do not stick firmly to the material of the filter, it is legitimate to look on filters of uniform structure as essentially sieves letting through particles whose diameter is smaller than the diameter of the largest pores present in the filter. This is the principle that was used in the first relatively accurate measurements of the size of different viruses. By careful arrangement of the conditions of preparation it is possible to make "synthetic" membranes of collodion of graded and nearly uniform pore size.

If we set up a series of such membranes whose average pore size is known from physical measurements, we can find

quite readily which membrane allows a given virus to pass. We start with a clarified virus suspension and under pressure pass ten cc. of it through each membrane. A portion of the filtrate is then inoculated into animals or embryos sensitive to the virus in question. Usually each filtrate will be titrated, i.e. tested at a series of dilutions to get a roughly accurate idea of how much virus gets through each membrane. The virus of vaccine lymph (vaccinia virus) that is used for vaccination against smallpox is larger than epidemic influenza virus and within a moderately wide range of error the correct size of these viruses was determined well before any electron microscope pictures could be obtained.

It is not quite true to say that viruses cannot be seen with any ordinary miscroscope. Some viruses can be stained with suitable dyes so that they appear as clearly defined dots under the highest magnification of a good microscope. An important method for the rapid diagnosis of smallpox depends on this fact. But at most no more than a colored dot can be seen. There is a simple physical reason for this limitation of the microscope. An object can modify the behavior of a series of waves only if it is not much smaller than the wave length concerned. If it is very much smaller it will have no more effect than a floating cork has on the waves of the sea. The wave length of green light is just about twice the diameter of a large virus like vaccinia virus, and this is therefore one of the smallest objects which can be seen.

The electron microscope depends on the fact that a beam of electrons can be made to behave in all essentials like a beam of light of a wave length about one-thousandth of that of visible light. In place of the glass lenses of a miscroscope the "lenses" of an electron miscroscope are electromagnetic fields of such a type as will bend the stream of electrons in similar fashion, so as to produce eventually an image of the object being looked at on a photographic plate or fluorescent screen. There are considerable technical difficulties in producing perfectly symmetrical and constant electrical fields, but theoretically there is no reason why the larger protein molecules should not be clearly seen, and the best photographs yet taken show clear detail at a magnification of over fifty thousand diameters. On

this scale a photograph of a housefly would show it about a third of a mile in length.

In practice it is by no means a simple matter to make effective use of these enormous magnifications. Even with ordinary bacteria one needs to use special staining methods to see them clearly under an ordinary microscope. The everyday routine of examining sputum or pus for tubercle bacilli depends wholly on a method by which the tubercle bacilli are left stained a different color from all the other bacteria that might be present. Techniques of that sort are not yet applicable to electron microscopy. One cannot, for instance, take a swab from the throat of a patient with possible influenza and put a smear of the material under the electron microscope to check at once whether the influenza virus is or is not responsible.

There are two main technical difficulties. First, the specimen to be looked at must be set up in a high vacuum and mounted on the thinnest possible film of cellulose. Glass is very opaque to electron beams, and it stands to reason that if we are going to produce a visible effect with something so minute as a virus particle, we must mount it on something not very much thicker and of the most uniform possible structure. The second difficulty concerns the material being looked at. Viruses can be obtained in the first instance only in extracts of infected tissues or in the fluids into which virus-damaged cells have been thrown off. Any such material when it is dried down on the cellulose film contains much more non-virus material than virus, and it is usually quite impossible to distinguish the virus particles from the debris of damaged cells. To obtain a satisfactory picture it is always necessary to purify the virus, using those techniques best suited to the problem in hand. For the larger viruses the use of a high-speed centrifuge alone will often produce satisfactory suspensions, but with some viruses all the tricks of modern physical chemistry may be needed to separate the "gold" from the dross.

Once a pure preparation of virus has been obtained it is placed on a carrier which consists of a tiny disk of fine wire mesh on which lies a very thin film of nitrocellulose. This is inserted into the vacuum chamber of the instrument at the point corresponding to where one places the slide in an ordinary micro-

scope, and then the whole system is brought to a high vacuum. Amongst other things this has the necessary result that everything on the carrier is completely dehydrated—the pictures are essentially of waterless skeletons of what the virus was in nature.

There are several ways of improving the pictures, using means essentially similar to the staining processes employed in bacteriological work. If the virus particles are treated with a chemical containing heavy atoms, osmic acid for instance, the "opacity" of the virus to electrons is greatly increased and a sharper contrast with the background obtained. Another ingenious method for enhancing contrast is by what is known as metal shadowing. For this technique the virus preparation on its cellulose carrier is placed in a vacuum chamber and "bombarded" at a certain angle by free atoms from a hot wire of the appropriate metal, gold or palladium. The atoms adhere to all surfaces that are not shielded by some object from the source of radiation. A spherical object on the membrane thus has the side away from the hot wire source uncoated and also throws a "shadow" where metal atoms have failed to cover the surface of the supporting film. By suitable photographic methods pictures can be obtained in which the heavily-coated parts appear white and the uncoated shadowed areas dark. These pictures give a striking three-dimentional illusion, virus particles looking like tennis balls scattered over a lawn.

In speaking of the sizes of viruses it is necessary to have some suitable unit, and in microbiology the units of length are the micron, written μ and equal to 1/1000 of a millimeter, and the millimicron (mμ), which is 1/1000 of a micron. Perhaps the simplest way to visualize the sort of magnitudes involved is to think of a series of spheres each one-tenth of the diameter of that preceding it. In the first, a centimeter sphere, one could comfortably house a fly, the second, one millimeter, would take one of the very smallest insects, the third, 100 μ, could be filled by a moderately-sized protozoön like paramoecium, the fourth, 10 μ would take two or three red blood corpuscles, the fifth, 1 μ or 1,000 mμ, would be filled by an average bacterium like the staphylococcus that causes boils. We are now approaching the size of viruses, for our next, sixth sphere, is almost the

same size as an influenza virus particle, and the seventh, 10 mμ in diameter, is a little smaller than the smallest known viruses, those of poliomyelitis and of foot-and-mouth disease of cattle.

Three or four typical viruses may be taken as covering most of the features seen in electron micrographs. First we can take the virus of psittacosis, which is a microörganism easily visible under the ordinary microscope when appropriately stained and, with a diameter of about 250 mμ, quite a giant amongst viruses. Electron micrographs show a picture which suggests that the virus is a spherical object surrounded by a rather firm skin, so that when the water is removed in preparing the specimen, the surface membrane collapses in folds around the central core of solid matter that is derived by dehydration of the body of the organism. Many virologists think that the presence of this surface membrane taken along with other characteristics of the psittacosis virus is sufficient for it to be excluded from the "true" viruses and given a class of its own.

The next of our types is vaccinia virus, which physically and in most other respects is nearly indistinguishable from the virus of smallpox. This is another large virus which when dried on the test membrane takes a rounded rectangular shape about 200 by 150 mμ. There is no evidence of a surface membrane, but there is an internal structure of some sort which in some ways resembles the nucleus of much larger organisms. When alive and containing the normal amount of water the virus particles are spherical or ovoid, and in this state were clearly photographed by ultraviolet light many years before the electron microscope.

Influenza virus is one which is particularly easy to study under the electron miscroscope by making use of the capacity of viruses of this group to attach themselves to suitable cells. By suitable treatment the red cells of the fowl can be made to liberate all their content of hemoglobin (the red oxygen-carrying pigment), leaving the thin surface membrane bulged in the center by the nucleus of the cell. Such cell "ghosts" dry nicely on the cellulose mounts and give clear photographs. If at the proper stage the cell ghosts are treated with a virus suspension, the virus particles attach themselves to the cell surface and show up very clearly in the electron pictures. There are two

well-defined forms in which the influenza viruses appear, spheres of about 100 mμ in diameter and long filaments of about the same diameter but up to 100 times that length. The filaments often show some evidence of regularly recurring pattern, but their relation to the spherical forms is not yet clear. . . . Incidentally, the long filament can be seen quite clearly under an ordinary microscope if one uses what is called dark ground illumination. The optical system underneath the specimen is so arranged that no light passes directly into the microscope—only things which, like motes in a sunbeam, are illuminated by light received more or less at right-angles are visible as brightly lit objects against a black background. A suitable preparation from chick embryo fluids will show many bright lines where the filamentous forms of the virus bend and waver in Brownian motion. The spherical forms are also visible, but as featureless spots of light which cannot be distinguished from other fragments in the fluid.

Finally, we may mention the virus of poliomyelitis to exemplify some of the difficulties of electron microscopy. Filtration methods suggest that the virus is very small, around 10-15 mμ in diameter, and it is obvious that in the infected tissues which are the only source of the virus, the actual amount of virus is very small indeed. If one grinds up normal tissues and carries out the same sort of process as is used in purifying virus it is easy enough to obtain minute granules of tissue particles of the same size as one expects the virus particles to be. This makes it very difficult, in fact almost impossible, to be sure whether the granules from *infected* tissue are virus particles or not. No one has so far been able wholly to convince workers in other laboratories that he has produced pure poliomyelitis virus and obtained its photograph by the electron microscope.

One thing that should be stressed about electron pictures of viruses is that they are representations of the *infective* form of the virus—what is liberated from the damaged cell and is ready to convey infection to the next susceptible cell. It is probable that for some viruses at least the form taken by the virus while it is multiplying inside the cell is very different. One of the main problems of the immediate future is to solve with the electron microscope or otherwise just how this multiplication

occurs.

The chemical structure of those viruses which have been obtained in pure form is more difficult to describe and interpret than their physical forms. Two have been particularly studied, the viruses of vaccinia and influenza. It would be easy enough to transcribe from textbooks and papers the elementary composition of each, so much carbon, nitrogen, phosphorus, and so forth. The result would be very much the same as the elementary composition of an average bacterial culture and would tell us nothing beyond the fact that virus particles are not very dissimilar from other living organisms.

Finer analyses have been made, and in broad terms we can say that both these viruses are largely made up of protein, much of it in combination with nucleic acid to form nucleo-protein which is generally regarded as the bearer of hereditary qualities in every type of organism from viruses upward. In addition, both contain fatty substances and complex carbohydrates. One unexpected component of vaccinia virus is a significant amount of copper, which may be a part of some enzyme mechanism, but for which no definite function has been found. By and large, chemical analysis indicates that viruses are simplified organisms made up of the same sort of building stones as other living material.

Perhaps it would not be an altogether unfair summary of our physical and chemical knowledge of viruses to say that it is rather similar to what our knowledge of motor-cars would be if it were limited to a specification of their over-all dimensions and of the relative proportions of iron, copper, rubber, water, oil, and petrol in their composition when on the road. Such knowledge would tell us a good deal, but it would leave us very far from being able to make a car or to understand the problems of traffic control in a modern city.

DONALD CULROSS PEATTIE

In Quest of Fern Seed

Donald Culross Peattie's charming piece about ferns—once the greatest branch of the plant kingdom—requires no comment. It is reprinted with permission of the magazine and Mr. Peattie, from the *Atlantic Monthly* for June, 1950, and from *A Cup of Sky* by Mr. Peattie, by permission of Houghton Mifflin Company. Mr. Peattie is the best-known of contemporary American writers on nature.

Full moon, on the night of May 10, 1941, guided the Luftwaffe to civilization's greatest target for destruction. On that night and the following, the German air fleet tried to burn and blast out the heart of London. The historic Temple was almost totally destroyed; the House of Commons, Westminster Abbey, the British Museum, the Fleet Street churches, the Mint, the Mansion House, and the Tower were either demolished or gravely damaged.

A few months later Londoners had piled the wreckage neatly and left the deep wounds clean, awaiting the day of peace and reconstruction. But in the meantime a strange flora rose in the bomb craters and the cellar holes seared by fire. Some of it was foreign weeds, such as a little plant whose Latin name of *Galinsoga* the Londoners changed to "gallant soldier." Others were quaint pastoral plants which you will find in Milton and Shakespeare. But most mysterious of all was the swift springing of the hart's-tongue fern wherever ground or wall had been blackened by fire.

In America the hart's-tongue fern is something so rare—growing in one county in New York State, one in Tennessee—

that many who would learn their ferns must travel far to see it in nature. Its simple, strap-shaped leaves uncoiling in springtime rear up like some ancient serpentine creature; the wavy-margined fronds at the bottom of the pool of green forest light have a seaweed look, and the whole plant, in its setting of limestone rock and spray from a cascade, breathes tranquillity and reserve. The American hart's-tongue is shy as the last of a vanishing race.

But life is seldom through with her children, even the ferns, now reduced to the smallest of all the subkingdoms in the plant world. To the hart's-tongue she has given the gift of fertility, which is all but immortality. On every leaf, on the underside, there are about eighty slender, oblique clusters of fertile capsules. About six thousand fruitful capsules fill each cluster, and in each of these crowd fifty tiny spores, light as pollen and viable as seeds. If each fern had only five leaves—and most have many more—then a single plant would produce one hundred and twenty million spores. And these have, it seems, the witchlike quality of sprouting best in burned ground, so that, blown from the English countryside, they came to cover with woodland green the broken stones of London.

I first knew the hart's-tongue fern in a rocky dell in southern France between the old walled village of St. Paul and the hamlet of La Gaude, a spot haunted by dreadful memories of the plague and by the pride and fall of the Templars, whose castle keep still stands near-by. I suppose that on that bank where the hart's-tongue grew among a drift of pale yellow primroses, under the shade of classic laurel and ilex, every good and bad thing one can imagine might well have happened. For that is always the way in such ancient ground; since the days of the Cro-Magnon man at least, perhaps ten thousand years ago, the hills above the Riviera have been continuously occupied, and sun-worshipers, stone-worshipers, oak-worshiping folk, have left their touch or sign on the place. And wherever there is worship, we are likely to find its dark side, fear; wherever a god walks, there goes a shadowing devil.

This I learned when I started out, in those Provençal years, to master all the ferns of the region. That was a simple task; there was only a handful of them—maidenhair and rusty-back,

spleenwort and goldilocks, male fern and lady fern, and bracken, or brake—twenty kinds, as I remember. It was not too hard to learn their names in English, Latin, French, and Provençal. But I seemed never to get to the bottom of all that men had believed and hoped and even feared about these ancient plant spirits. For ferns, which to a modern American are simply a choice and aristocratic component of a wood or a garden or even a drawing room, in Europe are the most hagridden thing still living.

For explanation I can only suggest—I do not know—that because ferns are what the botanist calls cryptogams (plants whose mode of reproduction was obscure before the days of the microscope) they earned the reputation of being unnatural. The simplest peasant could see that they had no flowers, neither did they bring forth fruit. Yet they increased—he guessed by some compact with dark powers. Fields that had been farmed in his grandfather's day—before the old wars—were taken over now by the bracken. Yet it had no seeds. When he turned the cattle in to browse it, they ate everything else but avoided it like poison (which in its mature stages it is). When he cut it with a scythe, he saw in the cut stem a pattern of the bundles of fibers that looked to some like an eagle with spread wings, to others like an oak. Some read in it the initials "JC." Was this profanity in the fern, or a seal upon it?

It was said, yea and by many believed, that the moonwort fern would open the locks of houses and of fetters and unshoe those horses that trod upon it. Thus did "the Earl of Essex, his horses, being drawn up in a body upon White Down in Devonshire," lose all their shoes. Gerard, the greatest of the English herbalists, called this fern martagon, and tells that the country people of his day believed that to sleep upon it would bring dreams and delusions.

No one knows why the ancients picked on two kinds of fern and called one male fern and one female fern, for of course they are not two sexes of the same species; but the choice was made so long ago that it was already old when Aristotle wrote his lost book on plants. To tell of all the "lovend and scurrilous matters" connected with the male fern is something that even

the herbalists shied from. Genghis Khan carried seed of male fern in his ring, and by it understood the speech of birds. To carry the seed in your pocket rendered you invisible. A character in one of Ben Jonson's plays explains:—

I had no medicine, sir, to walk invisible;
No fern-seed in my pocket.

We smile indulgently at this poetic fantasy, but the fern has a sly last word. From the time of Dioscorides, and long before, it had been believed that male fern taken internally was a vermifuge. A notorious quack sold a secret medicine to Louis XIV for fifteen thousand louis; upon analysis it turned out to be nothing but male fern. Actually that is still today the finest vermifuge.

The medieval and classic Europeans meant by female fern what now we call the bracken, the lustiest fern of the temperate zone. And about it grew up the strangest practices of all. Their origin comes down from the time when our ancestors were dwellers in a primeval forest, somewhere in northern or eastern Europe. They worshiped the sun and the oak, and their greatest festival was at the summer solstice, the longest day and the shortest night of the year. Even that brief night was, in honor of the sun god, illuminated with bonfires of oak wood. This custom they brought with them, as they moved into southern and western Europe; it was already thousands of years old when Christianity began to struggle with the widespread power of pantheism. Over the festival of the summer solstice it won but a nominal victory; it gave it a name, St. John's Day, but it could not exorcise all the elves and witches that capered in men's hearts upon that mysterious eve.

And none was so cherished, of all the practices of Midsummer's Eve, as the gathering of seed from the female fern. For on that night it bears a blood-red flower which is no sooner opened than its petals fall and are swallowed by the earth. But if you will spread a snow-white cloth beneath the fern at midnight, before the petals fall, you will catch too the magical deciduous seed. Get that seed but once in your possession, and the ground where you walk will become transparent. Thus you

can find where rich men have buried their treasure.

Here were dark matters! The Council of Ferrara, in its session of 1612, consulted anxiously and then decreed a prohibition against the gathering of fern seed on that particular pregnant night: *"Prohibemus ac vetamus ne quis ea nocte, quae diem S. Johannis Baptistae nativitatis sacrum praeit, filices, filicumve semina colligat."*

You and I know that ferns have no seeds at all, but the good fathers of Ferrara were relying upon a botanical opinion even then outmoded:—

> Although that all they that have written of herbes have affyrmed and holden that the brake hath nether sede nor frute, yet have I dyvers tymes proved the contrarrye. . . . I have foure yeares together, one after another, on the vigill of Saynte John the Baptiste . . . soughte for this sede of brakes upon the nyghte and indeed found it earlye in the mornynge before the daye brake. The sede is small, black and like unto poppye. . . . I gathered it after this manner. I laid shetes and mollen leaves underneathe the brakes which receyved the sede that was by shakyng and beatynge broughte out of the branches and leaves. . . . I went about this business, all figures, conjurings, saunter's charms, wychcraft and sorceryes set aside, takyng wyth me two or three honest men to bere me companye.

Most patently this antique herbalist had seen and gathered something real—something that he might have obtained on many another eve as well.

To a genius of whose life almost nothing is known must go the credit for first distinguishing between the seeds of flowering plants and the seedlike spores of ferns. Dr. Valerius Cordus (1515-1544) of Wittenberg in High Germany, where Hamlet studied and Dr. Faustus made his monstrous compact, realized that the "dust," as he called it, which grows upon "backs of ferns" was no true seed, since it has no nutrient store of food and no embryonic plantlet. Yet it is life-giving.

It took two centuries of work to unravel the life history of a fern. For ferns have an alternation of generations, such as

is familiarly understood in the case of caterpillar and butterfly. But ferns are more devious in their generations than this. The fern plant as we know it commonly is the sexless stage, for the spores it bears are neither male nor female. The sexual generation, which is produced when a spore falls to the ground and sprouts, is sometimes not as large as the nail of your little finger, and passes—when it is seen at all—for a first tiny shoot of moss or a little liverwort lying flat on the ground. Again, it may be colorless and subterranean, like some tiny tuber. On the upper surface of this sexual stage are borne the reproductive parts, the egg cells passive in a little open receptacle, the male cells fitted, like polliwogs, with tails for swimming. What they swim in must be rain water or even a film of dew; from the union springs again the airy arc of a fern plant.

This sexual stage would appear to be the weak link in the life history of a fern weak in structure, weak in dependence on conditions. But it has held through unimaginable ages. Ferns with their fern allies were perhaps the first plants on land, and still today when you see a horsetail fern growing where the *terra* is not quite *firma* you are gazing upon a form of stem and node and leaf and a mode of reproduction—spores borne in a conelike head—that is three hundred million years old. The ancestor of that plant, *Calamites,* was a giant in the great Age of Ferns, when through monotonous millennia the spores of those vanished forests drifted through the primordial damps to lay down the deep seams of our coal.

If ancient and distinguished lineage characterizes aristocrats, then the ferns are the most aristocratic plants that grow. They have other highborn traits. They disdain all gaudy display; they go in for refinement of detail; they are withdrawn in habit; and rather than live in an unbeautiful place, it seems, they would die. Nothing less than a green forest mansion will suffice the stately sword fern, the broad shield fern, the evergreen Christmas fern, the rattlesnake fern that our Southern mountaineers call "sang-sign"—sure sign, they mean (or hope), of the presence of "sang" or ginseng that they dig to be sold in the herb shops of far-off Cathay. The golden polypody crowns the tops of dry but shaded, lichen-covered boulders. The maidenhair loves dripping limestone cliffs. The filmy fern grows

only where it is forever wetted by the spray of a waterfall or the bubbling lip of a spring. And some, like the Cretan brake and *Cyrtomium*, the holly fern, which come from olden lands, will grow in America only on what little here is old—the walls of Fort Marion in St. Augustine, the mossy cemeteries of New Orleans.

So one by one you come to know them, first by their folk names of ebony fern and rue-of-the-wall, quillwort and baby fern, cinnamon fern and catwhistles, and then, as you discriminate, by their scientific titles. Moonwort easily becomes *lunaria*, spleenwort *Asplenium*, royal fern *regalis*. Many a fern's classic name sounds like a dryad's: *Dryopteris, Thelypteris, Lastraea, Pellaea*—they have a charm and chime that you yield to at last.

And many kinds will soon proclaim to you their identity as far as you can see them, above all by their way of carrying themselves, or, as with your human friends, by their oddities and foibles. The walking fern, for instance, has a little tongue-shaped blade whose overarching point, stabbing the forest loam, strikes root and sends up from it a new shoot, to go marching on, even as the old one fails, till, it may be, the elvish plant tip-toes silently away from the haunts where you knew it. The hay-scented fern is known by its sweet reek of silage, the ebony fern by its shining black stems, the rare climbing fern by its resemblance to smilax, while the adder's-tongue scarcely seems a fern at all but looks like some little jack-in-the-pulpit or other aroid. The flowering fern does not really flower, but so ample and fertile, so colorful and unleaflike, are its spore-bearing spikes that it looks, as its clusters rise above the broad green vegetative fronds, like a stalk in bud, a shoot that might flower, if some new miraculous kind of spring would dawn.

And that is what, ultimately, happened among the ancient ferns in the course of geologic ages. They and their allies, after millions of flowerless years, reached a stage of development where their spores were of two sorts, the small ones giving rise to an alternate generation which bore only male cells, while the big ones gave rise to plantlets bearing female or egg cells. At this point a botanist would be hard put to it to say why the small spores were not pollen, as pollen is strictly defined. More,

the sex generation, instead of existing as a separate plant, began to linger on the fern leaves, just as in flowering plants. Thus ferns developed seeds—true seeds, the result of fertilization of the egg cell by the male. So that, after all, there is, or there was once upon a Carboniferous time, such a thing as fern seed!

These seed ferns are the very species which, charred or drowned so long ago, became the bituminous and anthracite coal of today, and gave us murky skies and roaring cities. Better still, they gave us, by several evolutionary lines, the pines and cycads, at last even the queenly orchid and, not less, the homely, indomitable "gallant soldier" that, with hart's-tongue fern, sprang up in the shell holes of London.

THEODOSIUS DOBZHANSKY and
JOÃO MURÇA-PIRES

Strangler Trees

One of the basic assumptions of modern biology is the theory of evolution. No one in the ranks of science any longer seriously questions the power of life to adapt to changing circumstances, and the fact that the myriad of living forms now peopling the earth got here by an evolutionary process. The point of current interest is, how does evolutionary change come about?

It is easier to ask than to answer this question, because evolution is too slow a process to be directly observed at work. We have had to depend in the main on what could be learned from fossil remains—a not altogether satisfactory procedure since, among other things, conditions may not have been right for the formation of fossils at all stages in the earth's history.

In "Strangler Trees," Drs. Dobzhansky and Murça-Pires not only describe an odd manifestation of life in the tropical rain forest, but provide an insight into one way in which evolutionary change may occur. The article is reprinted, with their permission and the permission of the magazine, from the *Scientific American*, January, 1954 (Vol. 190, No. 1). Dr. Dobzhansky is professor of zoölogy at Columbia University and a widely known geneticist. Dr. Murça-Pires is head of the botany division of the Instituto Agronomico do Norte in Brazil and an expert on Amazonian plants.

Perhaps the most troublesome problem in the theory of evolution today is the question of how the haphazard process of chance mutation and natural selection could have produced some of the wonderfully complicated adaptations in nature. Consider, for instance, the structure of the human eye—a most

intricate system composed of a great number of exquisitely adjusted and co-ordinated parts. Could such a system have arisen merely by the gradual accumulation of hundreds or thousands of lucky, independent mutations?

Some people believe that this is too much to ask natural selection to accomplish, and they have offered other explanations. One school of thought suggests that evolution is directed not by natural selection but by some inner urge of organisms—an incrutable something called "psychoid." Another theorist proposes that the marvelous gifts of evolution to the living world came to birth through sudden and drastic "systemic mutations," which created "hopeful monsters," that were later polished down to the final product by evolutionary selection. But these theories amount only to giving more or less fancy names to imaginary phenomena: no one has ever observed the occurrence of a "systemic mutation," for instance.

Actually we do not need to meander so far from the Darwinian theory. There is no necessity for assuming that the human eye, for example, had a sudden birth or that cruder forerunners of it could not have been useful to their possessors before the eye acquired its final perfection. The ancestors of the human species had eyes to see with, though they may have been less elaborate than ours. In short, the eye could have developed gradually from a very simple organ which in its earliest form gave some kind of "sight" or other useful ability to the animal that possessed it.

We shall consider in this article a most remarkable adaptation in the vegetable world which illustrates such a step-by-step evolution. In some exuberant rain forests of the tropics there grows a strange variety of plants known as strangler trees. Such a plant starts by seeding itself and growing like a vine on the trunk or branches of an ordinary forest tree. Climbing over its host, the strangler enfolds it in a thick mass of roots, strangles it to death, and finally stands on its own as an independent tree!

The reason for the origin of the strangler trees (of which there are a number of species) is plain. In the dense tropical forest the competition for sunlight is keen. A young plant sprouting on the dark forest floor has a poor chance of survival unless

it can somehow break through the canopy overhead. The stranglers have solved the problem by climbing on other trees. And the whole life history of these outlandish trees seems beautifully contrived to accomplish their objective: to seize a place in the sun in the midst of a dense tropical forest. How could this singular adaptation have arisen? Here is an extraordinary example of just the kind of complex adjustment that seems to justify some esoteric explanation such as "psychoids" or "systemic mutations." Let us see, however, whether a simpler explanation may suffice.

We need to consider first the life history of a strangler tree. Among the most common stranglers are certain fig trees (genus *Ficus*) of Brazil. The seeds of the strangler fig usually sprout high on the branches of a tall tree; just how they get there is not well known, but there are reasons to believe that they may be carried by birds and fruit-eating bats. The young seedling produces roots of two kinds. One kind grows around the branch or the trunk of the supporting tree; the other descends toward the forest floor, either along the trunk or hanging in the air. The stem of the strangler sprouts leaves and grows upward to catch the sunlight. The young plant gets its water and its mineral food from accumulations of dirt and organic matter in crevices of the tree's bark. At this stage the future strangler is not a parasite, for it derives no nourishment from the living tissues of its host. It is an epiphyte, i.e., a plant which grows on another plant.

As soon as the descending roots take hold in the soil of the jungle floor, the growth of the strangler quickens. Its roots rapidly thicken and harden, and it puts out many new branches and leaves. It is often difficult to tell from the forest floor which foliage belongs to the strangler and which to the host tree. New roots are formed, and they begin to branch on the surface of the supporting trunk. Eventually they form a mesh which envelops the host tree with an ever-hardening strangle hold. The appearance of a gigantic forest tree caught in the deadly embrace of a strangler is weird in the extreme. It makes one think of some of the grotesque creations of surrealist art, but it has the nobility and the purposefulness of life.

Now the strangler proceeds to kill the supporting tree. It

does so not merely by preventing the trunk from expanding but actually by squeezing the tree. This is indicated by the fact that the strangler fig often kills palm trees, whose trunks grow steadily in length but little or not at all in thickness.

While the fig is throttling its host, its roots go on growing and hardening, until they completely or almost completely cover the trunk. They also form buttresses which enable the fig to stand on its own feet. By the time the supporting tree dies, the strangler has become an independent tree, with its own crown of branches and leaves. Many specimens of these figs reach colossal dimensions, rivaling in height and girth some of the giants of the tropical forest.

At the final stage of its development the strangler may or may not show outward signs of its murderous past. Its "trunk," which in reality is a mass of fused roots, often has a bizarre shape, owing to the many cable-like or plank-like buttresses. But it may also attain an almost regular cylindrical shape. In either case its true nature is readily exposed if one cuts through the mass of roots: inside there is a cavity which contains the more or less decomposed remains of the victim. Near Belém at the mouth of the Amazon stands a gigantic fig tree which has grown on the tall chimney of a brick factory abandoned some seventy years ago. The chimney is now all but invisible.

The Brazilian figs, which belong to the mulberry family, are one of many kinds of stranglers. Strangling trees are common not only in Brazil but also in rain forests of Australia, New Zealand, and other places. But now, from the point of view of how the strangler trees evolved, we note a highly significant fact. There are many strangler-like plants which do not strangle their hosts. A notable example is the Brazilian tree called *Clusia*. Some species of this genus behave like the strangler figs in every respect except one: they seldom if ever kill their support. We have seen thousands of jungle trees attacked by Clusia, and all of them were alive. High up in the forest canopy the large, leathery, dark-green leaves and the showy, rose-colored flowers of Clusia mingle with the foliage of the host tree. Adolfo Ducke, the leading authority on Amazonian flora, has informed us that he cannot remember having seen a Clusia that caused the death of its host tree.

Clusia may, then, illustrate an important stage in the evolution of the strangling habit. It is well adapted to use other tree species for support, and it is able to cling quite firmly to its host. But it stops short of killing the host tree and taking its place. When the host tree dies, Clusia presumably perishes with it, although further observations on this point are needed.

Still earlier stages in the evolution of the strangling habit may be seen in Brazil in three genera of plants of the mulberry family, to which the figs also belong. These genera are *Coussapoa, Pouroma* and *Cecropia.* Unlike the strangler figs or even Clusia, they may start in the soil on the forest floor and grow for their entire lifetime without climbing on other trees; they often grow in this independent fashion in forest clearings. The three genera show varying degrees of epiphytism: Coussapoa acts as a strangler frequently, Pouroma less often and Cecropia only occasionally.

It is remarkable that the strangling adaptation has evolved independently in several quite independent families of plants. The forests of New Zealand have no strangler figs or other stranglers of the mulberry family, but there is a strangler there called "rata" which is a member of the myrtle family. A rata kills and replaces its supporting tree in just the same way as a strangling fig. Yet a species closely related to rata grows on trees like a vine without strangling them.

E. J. Godley and L. J. Dumbleton of New Zealand have called our attention to still other plants in New Zealand forests which furnish striking illustrations of the probable stages of the evolution of the strangling habit. These plants belong to several different families: *Weinmannia* of the family *Cunoniaceae, Schefflera* of the *Araliaceae, Melicitus* of the *Violaceae* and *Griselinia* of the *Cornaceae.* Yet these rather remotely related plants are all capable of growing either as stranglers or as independent trees from the soil. It is not difficult to see how their versatility has evolved. The trees that they victimize most often are tree ferns—whose beautiful feathery fronds are so characteristic of the New Zealand forests. The trunks of the tree ferns are covered with a spongy mass of fibers, which in the rainy climate of many parts of New Zealand provides an inviting medium for seeds. Various species of plants have seized

the opportunity and evolved adaptations which permit them to grow on such trees. After a time the evolving climber may lose the ability to start its life without the support of another tree; it is no longer a facultative strangler but an obligatory strangler. On the other hand, some members of the same plant genus or family keep their ability to grow independently.

Evidences of such evolution can be seen not only in New Zealand but also in the forests of Brazil. Some of the fig species there grow into huge trees without ever resorting to the strangling techniques of their relatives.

To summarize, a comparative study of the strangler trees shows that these amazing representatives of the plant kingdom possess quite a variety of adaptations for life under the exacting conditions of the tropical forest. The origin of these adaptations can easily be visualized as being due to nature's selection of useful hereditary modifications. This view is in accord with the modern theory of evolution, which considers selective responses of the organism to opportunities in the environment to be the primary driving force of the evolutionary process.

WILLIAM HOLMES

The Color Changes of Cephalopods

As Dr. Holmes explains, cephalopods are creatures with arms near their mouths. The name stems from the Greek and means "head foot." A most extraordinary feature of the cephalopods, a group that includes the squid, the octopus, and the cuttlefish, is their ability to change color. Dr. Holmes explains how this is done in his article, which is abridged by permission of the journal, from the April, 1955, number of *Endeavour*, the excellent scientific quarterly published by Imperial Chemical Industries, England's leading chemical company.

The cephalopods are so called because they have developed long "limbs" near the mouth, a feature which is among those distinguishing them from lower mollusks, such as snails. The octopod mollusks (e.g. *Octopus*), use these structures both as arms in feeding, and as legs in locomotion. The decapods (e.g. *Sepia*, the cuttlefish, and *Loligo*, the squid) use them as arms only, and move themselves about either by the undulations of a fin which runs down either side of the body or by the expulsion of a jet of water from one of the body-cavities.

The most primitive mollusks undoubtedly had a shell, which is a protection against many sorts of predator. But a shell is a cumbersome thing, restricting activity, and the evolution of the group involved exploring new food sources inaccessible to an animal with a heavy shell. Accordingly the cephalopods developed the arms and the jet-propulsion mechanism; at the same time they gave up the shell as a protection. In decapods the shell remains only as the "cuttle-bone," lying below the skin; this gives little protection, for it does not cover the head.

The power of changing color is a new, alternative, protective device, and since it was acquired by mollusks late in their evolution it is not surprising that it is brought about by a unique mechanism. Other animals use color and color change as a means of stimulating, deceiving, or frightening each other or their predators or their prey, but the underlying processes are different.

Sometimes the body of a recently dead cuttlefish or squid is found on the seashore; even if it has been dead for some hours the chromatophore activities which are the basis of color change may still be seen taking place: waves or clouds of color pass over the surface of the body, changing continuously and in a matter of seconds. The waves of color show variations on black, brown, red, and yellow. The general effect is the result of the activity of large numbers of individual colored bodies in the skin—red, brown, or orange-yellow—on a background of pearly, iridescent white. Each of these bodies varies in size from an almost invisible pin-point to a maximum which depends upon the species, but is as big as a pin's head or larger.

The chromatophores have been studied for many years, and it has long been known that each is a hollow sac with elastic walls, containing pigment granules; the chemical composition of these is still not known with certainty. Connecting the outer wall of the sac with the adjacent tissues are fibers of unstriped muscle radiating outward in the plane of the surface of the body. Contraction of the fibers pulls the sac outward into a flat disk, spreading its colored contents over a wide area; when contraction of the fibers ceases, the elasticity of the sac reduces it again to a pin-point sphere. Many studies have been made of the physiological properties of these minute muscle fibers. The rate of expansion of a chromatophore may be measured photoelectrically; the change from complete contraction to full expansion can occur in two-thirds of a second. The muscle fibers seem immune to fatigue, for their response is undiminished after effective stimulation for thirty minutes at a frequency of thirty shocks per second.

The chromatophores lie in three layers in the skin, the yellowish ones on top, the red in the middle, and the brown or black below; they overlap each other when expanded, and con-

sequently various compound color effects result. The pearly background color is the result of reflection of light from a layer containing structures of a different character, called iridocytes. These are incapable of changing shape, but on certain areas of the body they are aggregated into clumps, which shine clear white; these, as we shall see, play a part with the chromatophores in the formation of color patterns. Some of the clumps of iridocytes are, in a sense, mobile for the skin containing them may either lie flat along the body or be arched up into conspicuous papillae.

Protective Coloration

Animal colors can be classified into several categories according to their adaptive value; that is, according to the way in which they affect other animals of the same species, or animals of a different species in the same environment. Thus, its color may cause an animal to resemble features of its immediate environment, rendering it more or less invisible to its enemies, who cannot distinguish it from other adjacent, inedible objects. Resemblance to its surroundings is equally valuable to an animal which is a predator, for then it can steal upon its prey unobserved. Again, we may have warning coloration: an individual may be equipped with bright colors, or colors arranged in striking patterns which are associated with effective weapons of defense or the ultimate protection of nauseous taste, or inedibility. By this last device the predator is trained to avoid other members of the race, though the individual is sacrificed. Another use of color is that associated with the breeding habits of the animal, in which a particular play of color, or a particular pattern, affects members of the opposite sex of the species, or competing members of the same sex. . . .

Color Patterns of the Cuttlefish

A cuttlefish swimming undisturbed in a large aquarium shows a "zebra" pattern. Down both sides of its back run broad stripes, alternately dark brown and almost white; similar stripes appear over the large lateral arms. . . . The fin has a pale brown mot-

tling, and the underside of the body is white. In the black stripes the dark chromatophores are almost fully expanded; in the pale areas they are fully contracted. The pale areas vary in color from orange to white, according to the degree of expansion of the lighter-colored chromatophores; the purest white is seen when the light is almost all reflected from the iridocytes beneath. An area in the middle of the back, shaped like the cuttle-bone and lying over it, is mottled in color when the animal is in a small tank which obliges it to be always near the bottom or sides. In a large tank, the zebra stripes pass over the whole of the dorsal surface, though they are narrower over the cuttle-bone. . . .

The ventral (lower) surface of the body is pale, and this difference between upper and lower surfaces demonstrates the first principle of protective coloration: that of "obliterative countershading." The dorsal (upper) surface receives most incident light, and reflects least; the ventral surface is in the shadow, and reflects almost all the light that falls upon it. This counteracts the normal effects of light and shade, which give the appearance of solidity to a body; thus the animal is protected by an artificial vagueness given to its form. If a cuttlefish is turned upon its back, as it must often be when fighting, the dark chromatophores of the ventral surface instantly expand, and so minimize the dangerous conspicuousness which would otherwise arise when the light fell on its white belly. The protective value of the black and white stripes needs no emphasis; these serve, as they do for the zebra, to disrupt the shape of the body, and so to make it inconspicuous. The cuttlefish often swims among beds of waving seaweed, and when near the surface ripples of light and shade fall on it, adding to the deception.

Another environment in which cuttlefish are often found is shallow coastal water where the sea-floor is sandy or composed of shell gravel. When swimming close to such a bed the animal modifies its stripe pattern by a partial contraction of the dark chromatophores and further expansion of those of lighter shade. Thus it comes to match its background, having much less contrasted stripes, of a sandy color, on its back, resembling the play of light on the sandy sea-bed. If it settles down on the

sand the stripes disappear altogether, leaving a mottled pattern of an appropriate matching color, resulting from reflection of light from the three types of chromatophores, variously expanded, in irregular patches. This pattern covers the head and arms as well as the back.

We now come to the white-square and stripe patterns, which can easily be elicited from animals in a small tank. If one blackens the floor and walls of the tank a cuttlefish placed in it receives comparatively little incident light. Its response is to become uniformly very dark in color, by full expansion of the black chromatophores; it is thus made inconspicuous. If now a white object, such as a porcelain plate, is introduced, clear white areas appear on the body. Three main elements may be distinguished in the black-and-white pattern: a stripe across the head above the eyes; a square in the center of the back; and symmetrical white bands extending down at either side of the back from the central square. The square may appear either with or without the white stripes. As protective devices these patterns are useful both by giving a resemblance to the environment and by disrupting the outlines of the body. They are often accompanied by another kind of white pattern on the black background, brought about by the muscular elevation of papillae containing a concentration of iridocytes; these arise in regular positions along the base of the fin. . . .

Perhaps the most remarkable of all are the "terrifying" patterns, which appear and disappear with lightning rapidity. Strong stimulation of the cuttlefish is followed by a series of color changes of remarkable rapidity, involving the whole body of the animal. A succession of patterns is exhibited, each one enduring for a few seconds only. A strong touch, a violent movement in the visual field, or a disturbance of the posture of the animal, are each sufficient to elicit these changes.

Usually the first result of disturbing the animal is the appearance of two black spots, which arise symmetrically on the back, always in the same position. If the animal is fairly gently stimulated, a single spot will appear on the same side of the body as that to which the stimulus was applied. The appearance of the black spots is very soon followed by a total paling of the whole of the rest of the body, so that the spots stand out

with startling clarity. This pallor is rarely maintained for more than a second or two, being usually succeeded immediately by a complete change, the total blackening of the body. On further irritation a new pattern may appear: two longitudinal black stripes appear on the back, and the rest of the body turns white again. The lines flicker vividly over the pallid back. The animal's final resource is to eject a cloud of "ink"; having done this it becomes motionless, and hides inside the black cloud. The cloud remains suspended in the water for a considerable time, and makes further observation of the color of the animal itself impossible. The sudden display of a conspicuous pattern of color is known, among other animals, to be a form of warning coloration. The "terrifying" displays of the cuttlefish may also protect it in another way. The rapid changes from black to white make the animal seem to disappear, even to the acute human eye, and the sudden movement of the conspicuous colored shapes may startle and divert the predator.

Each particular situation in the cuttlefish's life evokes characteristic color behavior. . . . No other cephalopod has as extensive a repertoire of patterns. The octopus shows some comparable changes; but the squids, which live in deeper water, though capable of generalized changes, cannot produce conspicuous patterns. These open-ocean creatures often show instead patterns of luminescence in the dark, but they are so difficult to keep alive in aquaria that few have studied them.

REGINALD D. MANWELL

An Insect Pompeii

When we think of fossils, we are apt to think first of the fossil remains of dinosaurs and other great creatures that once roamed the earth. Other orders of the animal kingdom have a no less interesting tale to tell, however, as witness this article. "An Insect Pompeii" is reprinted, with the permission of the American Association for the Advancement of Science, from the June, 1955, issue of the *Scientific Monthly*. Dr. Manwell is professor of zoölogy at Syracuse University and an expert on malaria. He has made fossil insects a hobby, because of the close connection between insects and diseases like malaria.

Pompeii and Herculaneum are famous in human history because of the great disaster that overtook them in the catastrophic eruption of Mount Vesuvius in A.D. 79. But the tragedy that suddenly snuffed out the lives of so many Romans proved good fortune, of a sort, for posterity. Had not those prosperous Italian cities been so suddenly overwhelmed and buried by the mud and ashes from the angry volcano, we should certainly now know much less of Roman life of the first century.

Few people are aware of a similar series of catastrophes that befell a small segment of the insect world some twenty-five million years earlier in central Colorado. In Miocene times, long before the Rocky Mountains reached their present majestic height, there occurred in that area a number of volcanic eruptions. One of the volcanoes, of which little trace remains today, was situated near what is now the little hamlet of Florissant, a community too small even to keep the railroad it once had. About twenty miles east of the town is Pike's Peak,

and not far to the east of that, the Continental Divide. Florissant itself is now about 8200 feet above sea level. But in Miocene times its site was much lower, and the climate was apparently subtropical and moist, since the fossilized remains of palms and sequoias have been found there. Nearby was a beautiful lake, although evidently a small and shallow one. High promontories reached out into it, and there were a few islands which must have added to its beauty. In more recent times the whole area has tilted sharply toward the northwest, with the result that the lake was drained dry, much as one might empty a saucer.

But the volcanic eruptions that created so much havoc to myriads of insects, and no doubt to other life of the region as well, occurred long before the lake itself disappeared to become what we might call a fossil body of water. Instead of the great outpouring of mud and ash that inundated Pompeii and Herculaneum, there must have been successive showers of much finer dust, interspersed with occasional coarser material. Whether the insects were first killed by toxic gases, such as the hydrochloric and hydrofluoric acids often present in volcanic emanations, or were simply carried down by the heavy dustfall into the waters of the lake, we shall never know. Doubtlessly similar events have happened many times in other parts of the world, both in the distant and more recent past, and are still happening.

But conditions at Florissant were different. There, under the quiet waters of the lake, the gradual transformation of the volcanic debris into the soft and delicately layered shale that we find today began. On these sheets of rock, some of them almost paper-thin, we find inscribed a kind of pictorial history of the insect and plant world of that remote time. Many of these luckless creatures left fossil imprints exhibiting a perfection of detail surpassed only by the equally famous fossil insects found in Baltic amber.

That animals so small, and with bodies as delicate as those of many insects, should leave any fossil remains at all is remarkable, and such fossils are known in abundance from only a few localities. Although probably few of its tiny population realize it, Florissant is famous throughout the entire entomo-

logic and paleontologic world for its insect graveyard. The scientific value of these remains is enhanced not only because they are representative of a very different region, but also because they are of a quite different period from the older fossils found in Baltic amber. The latter are believed to be of the Oligocene period, and the former are regarded as Miocene. Thus, some fifteen million years may separate them, and Florissant fossils are perhaps twenty-five million years old.

The shales formed from the volcanic detritus accumulated to a depth of at least forty-five to fifty feet, but much of the original deposit has long since been eroded away, and by no means all its layers contain insect fossils. Some of the strata show only charred bits of wood and twigs or beautifully delineated leaves. There are also a number of petrified sequoia trunks in the near neighborhood, some of which are said to have been twelve or fifteen feet high when discovered. Now, because of the toll taken by souvenir-hunting tourists, most are scarcely three feet above the ground, or are only just visible. The largest of them was from ten to twelve feet in diameter.

The fossil hunter, if he is interested in doing his own exploration, may hunt for outcrops of shale and then break away pieces with a light pick or geologic hammer. But the material weathers so quickly after exposure that it is often better to take advantage of the fossil quarries already established, the owners of which are very courteous in their treatment of scientists. In either case, it is necessary to use a good deal of patience. Insect remains are not like those of dinosaurs. They often require the use of a good hand lens to make them out clearly, although there are compensations. They are much more likely to be found intact and do not require reassembly, as do dinosaurs, although in either case, of course, only the skeletal parts are preserved.

The shale, however, is likely to crumble after drying—it is usually moist when first uncovered—and it must be handled with care. A protective coating with some substance such as shellac prevents peeling and chipping and makes the finer structures much more visible.

Although insect remains are by far the most numerous of the animal fossils preserved at Florissant, other groups are also

represented. The shells of tiny fresh-water mollusks are not difficult to find entombed in the rock, and, occasionally, even the skeletons of fish and birds are seen. Several hundred species of plants have been identified from these shales, usually from leaves, but fruits (that is, nuts) and even blossoms have also been found. Among the types recognized have been sequoias, palms, oaks, conifers (other than the sequoias), maples, elms, roses, and various legumes. It is said that the plant types collectively suggest a climate similar to that now found on the more northern shores of the Gulf of Mexico.

Insect life around and above Lake Florissant must have been very abundant, for it is not unusual to find on a single small piece of shale from one of the richer fossiliferous layers several individuals within two to three inches of one another. This life was extremely varied, with the total number of species running into the hundreds. Most of the larger orders of insects (such as ants, wasps, bees, true flies, beetles, weevils, and true bugs) are well-represented. . . . Members of other orders also occur. For example, occasional specimens of *Odonata* (dragonflies and damsel flies) are found.

It is rather difficult to compare the relative abundance of these groups today with that of Miocene times, some twenty or twenty-five million years ago, because to make an accurate comparison would involve finding an existing environment just like that of ancient Lake Florissant. Essentially, however, it appears that the insect world has changed relatively little in that vast period of time. All but one of the presently existing twenty-five orders were then in existence, and most of them were already very ancient. No one can say just when the first insects appeared, but fossil forms (much like some we know today) have been found in rocks of the Upper Carboniferous (late coal-forming) period, dating from about two hundred million years ago.

Numerous genera and species have become extinct, and the distribution of others is much different from what it was in Miocene times; yet many forms known as fossils from Florissant shales still survive virtually unchanged. This must be considered an especially remarkable fact when one recalls the short life-span and, hence, the number of generations there must

have been since that remote epoch.

Nevertheless, it seems certain that some groups were more numerous then than now. Samuel H. Scudder commented on the "prodigious number of ants" (about twenty-five per cent of the total) represented in the insect fossils of Florissant, and the true flies (*Diptera*) were the second most commonly encountered group. Today the beetles (*Coleoptera*) vie with the flies for the distinction of being the largest insect order, although in North America it is said that there are some 25,000 species of the former as against only 15,000 of the latter. The relative abundance of the two at Florissant was therefore reversed. But it must be remembered that climatic conditions in Miocene Florissant were quite different from those in most of North America today. Doubtless the season of the year when the eruptions occurred was also a factor in determining the relative abundance of different groups. It has been suggested that the eruption that resulted in the deposition of the richest fossiliferous layer may have occurred in the spring, because of the nature of some of the plant remains and the abundance of March fly (*bibionid*) fossils.

Not only have insects apparently undergone little structural change in many millions of years, but also their habits, at least in many cases, remain much the same. This is indicated by many similarities, both in form and type, to closely related groups today. The ants were divided into castes then as now, with winged reproductive forms and wingless workers. There were also many chalcids—often called flies but really tiny wasps—a family in which most of the members, during their larval stages, parasitize other insects. In some modern species (and hence, very likely, in some of these fossil types) the chalcid larvae even parasitize other parasites.

Then there were the ichneumon and braconid flies, actually like the chalcids in also being wasps. Both types parasitize other insects and play a very important role in the maintenance of biological balances.

It is also certain that warble flies were abundant. Their larvae feed on mammals, in the flesh of which they develop until ready to pupate. Fossilized warble fly larvae and pupae, presumably dropped from some mammalian host, have been found in shales

even older (Eocene) than those at Florissant in both Colorado and Utah. These must surely be among the oldest fossilized internal parasites known.

Among the true flies that seem to have been abundant about Lake Florissant were also the mosquitoes, *Culicadae*, and the midges, *Chironomidae*, although unfortunately so far almost no forms of either group have been found showing wings. Nor have fossil larval stages of either been seen yet, although they must have been present in great numbers in the shallow waters close to the reedy shores.

The presence of mosquitoes makes one wonder whether mosquito-transmitted diseases, such as malaria, already plagued the terrestrial vertebrates of the world. Birds were certainly numerous, and malaria is a very common infection in many avian species, particularly the perching, or passerine, types, fossil remains of which have been found in the Florissant shales. There had presumably been ample time for the malarial parasites to have evolved their present mosquito-vertebrate cycle, for mosquitoes are known from Eocene times, thirty-five million years, more or less, earlier than the Miocene period.

In this connection, it is interesting to speculate about how and when malaria originated. Even today, with all that has been accomplished in some countries toward its control by the use of DDT, malaria is still probably the most prevalent of human diseases. The malarial parasites that attack the lower animals are of different species from those that attack man, but this group of parasites (genus *Plasmodium*) are all very closely related.

Perhaps the malaria plasmodia were first parasites of mosquitoes. Later, after being introduced into vertebrates in the process of bloodsucking, some of these parasites proved adaptable enough to continue life in their new environment and yet have retained the ability to live in the mosquito host whenever opportunity came. Thus the typical mosquito-vertebrate cycle may have originated.

Perhaps reptiles were the first vertebrate hosts of malaria, especially since they are still subject to infection by various species of plasmodia. Birds and mammals both evolved from reptilian stock and thus, in a manner of speaking, very likely

inherited malaria from their saurian ancestors. But it is certain that neither man nor any of his simian and anthropoid relatives suffered from malaria inflicted by mosquitoes breeding in ancient Lake Florissant, since no primates existed there at that time.

Disease, however, is undoubtedly as ancient as life. Indeed one might say that disease is almost a biological necessity, for without it the delicate balance that exists between all living things and their environment would be much more difficult to maintain. Famine and even more ruthless competition than already exists in nature would have to take over the role of the pathogenic parasites. That such parasites have existed for a very long time is suggested not only by the great antiquity of mosquitoes but also by the discovery of fossil tsetse flies of Miocene age in Florissant shales. At present the latter are restricted to equatorial Africa, where they are of great importance as transmitters of human sleeping sickness (*trypanosomiasis*) and some closely related diseases in domestic and wild animals.

One cannot but wonder whether some of the numerous species of mammals then living in North Africa, and now extinct, may not have perished from the earth as the result of similar tsetse-borne diseases. It is also tempting to speculate on how different the history of the New World might have been if these flies had remained as widespread in their distribution as mosquitoes still are, for civilization and diseases such as the trypanosomiases of man and domestic animals simply do not mix.

We can only guess at the factors that may have caused the range of the tsetse fly to contract to its present much more restricted area. Quite possibly, it was the repeated glaciation that covered so much of the temperate regions of the Northern Hemisphere and greatly changed the climate even where there was no ice.

Fossil deposits such as those of Florissant not only intrigue the imagination, when we try to picture the world so far off in time that existed then, but also perhaps raise more questions than they settle. Not only does the finding of fossil insect types that are now important as vectors of disease-producing parasites make one wonder whether they played the same role then,

but it poses many other questions about evolution. How rapidly do new species, genera, families, and larger groups evolve? Why do some types apparently evolve more rapidly than others? Did evolution occur faster in some geologic periods than in others?

From the biologist's point of view it is most unfortunate that so little attention is being given to the study of insects of the past. Although it is virtually certain that the insect fauna of more remote geologic time was at least as varied and abundant as that of today, only some 13,000 fossil species are known from the entire world. A more complete knowledge of insect fossils would shed much more light not only on the evolution of that group but on other problems (such as those of climatic changes) as well.

We may also wonder whether insects have evolved more rapidly—or less rapidly—than mammals. The former are more ancient by at least some 60 million years, since the oldest known insect fossils (but certainly not the first insects) date from the Upper Carboniferous (coal-forming) period, which ended about 220 million years ago. There are also far more species—at least one million of insects, as against possibly 5,000 of mammals. Some 3,000 more of the latter are known as fossils.

Although the insect world in Miocene times, as revealed by the fossils in Florissant deposits and those from other deposits of like age, was not very different from that of today, the mammalian fauna would have presented a sharp contrast. No North American series of mammalian fossils of just the same age as the Florissant insect remains is known, but we do know that most of the genera of mammals existing then are now extinct. Instead of the familiar species of the present, hyenas, rhinoceroses, camels, wild horses, and elephants might have been seen. Perhaps there were still even a few of the great titanotheres (rhinoceros-like), mammals of immense size and now wholly extinct, ranging the plains and grassy uplands. Man, of course, did not arrive on the scene until perhaps one million years ago, and did not reach North America (according to George Carter of Johns Hopkins University) until, at the most, perhaps 100,000 years ago—hardly yesterday to a biologist.

The study of the records of a time so long ago that we cannot even call it a forgotten epoch thus sheds light on many im-

portant problems of the present but raises more problems than it solves. For life is a kind of clock and, like all clocks, refers only to the present, but has meaning only in terms of the past, since the future cannot be known. What time may hold in store for the insect world, for mammals, or even for man, the records of past ages only hint. But whether the human species has a long future ahead, or whether—like the titanotheres that vanished after millions of years of apparent success—it is destined to early extinction, we may be sure that, until the end, man will continue to be fascinated by the story told in ancient rocks, such as the volcanic shales of Florissant.

OSMOND P. BRELAND

Which Are the Biggest?

There are many questions that may be asked about the creatures that share the world with us. A favorite is ever "Which Are the Biggest?" Dr. Osmond P. Breland's answer is reprinted in abridged form from the February, 1953, issue of *Natural History*, the magazine of the American Museum of Natural History, with the permission of the magazine and Dr. Breland. Dr. Breland is a University of Texas zoölogist.

One seldom hears a hunter boast of the smallest animal he ever killed; nor do fishermen vie with each other to see who can catch the tiniest fish. Although people are interested in the unusual or exceptional, they are usually more attracted by the very large than by the smallest of objects or achievements.

When one thinks of the giants of today, he usually pictures the elephant or the sulphur-bottom whale. Yet among lesser creatures there are record-holders that are just as spectacular in their own sphere.

Protozoans, for instance, have only a single cell in their bodies, and we would thus not expect them to compare in size with the largest of other groups. Some of the protozoans are responsible for serious human diseases such as malaria, leishmaniasis, and amebic dysentery. Most of them are so small that they cannot be seen with the unaided eye. On the other hand, there are comparatively mammoth protozoans, and Dr. Theodore Jahn, of the University of California, states that there is a greater range in size among the Protozoa than in any other group of animals.

One of the smallest protozoans is the one causing kala azar, a type of leishmaniasis in human beings. Even husky specimens may be only 1/25,000 of an inch long. The largest of the protozoans belong to a group that is parasitic on fish. One kind (*Myxobolus*) causes what is known as boil disease in certain European fishes, and individuals may be nearly three inches long—surely a decent size for one cell! Dr. Jahn has estimated that the largest protozoan has approximately two quintillion times the volume of the smallest one!

Jellyfish are comparatively simple creatures, and the bodies of many of them are composed of more than 96 per cent water. But any swimmer who has contacted the stinging cells of a large jellyfish knows that they must be regarded with respect. The body of a large jellyfish consists of a rounded mass of jelly-like material, which is sometimes called the bell. Around the margin of the bell there are attached a large number of long strandlike appendages called tentacles. In view of the comparatively simple structure of these jellyfish, it is amazing how large some of them grow. Professor Louis Agassiz, one of the best known of the early American biologists, measured a specimen found off the Massachusetts coast, and its bell was 7½ feet in diameter. Its tentacles were more than 120 feet long! Others with bells twelve feet across have been reported. There is no animal known, either living or extinct, with appendages or body as long as the tentacles of the largest of the jellyfishes. As we shall see, however, some are almost as long and considerably more bulky.

The name "worm" is used for any kind of soft-bodied animal that is very long and slender, and there are a multitude of different sorts, such as earthworms, tapeworms, hairworms, flatworms, and roundworms. There are also many other kinds of worms, including some that live in the ocean, called proboscis worms, or nemertine worms. They are called proboscis worms because they have a long tube or proboscis, that they can project at the front of their bodies. This they extend from time to time to grasp some small creature for food. It is somewhat debatable what kind of worm should be given the title of the world's largest, but the two outstanding competitors seem to be the proboscis worms and the tapeworms.

The proboscis worms have great powers to expand and contract their bodies, and one of the largest measures eighty to ninety feet when fully extended. It is quite possible that there are individuals more than a hundred feet long.

Tapeworms, of which there are several kinds, are well-known parasites in the human intestine. People become infected with certain kinds of tapeworms by eating improperly cooked fish, beef, or pork in which infective stages of the parasites are sometimes found. The beef tapeworm and the fish tapeworm are the largest of the tapeworms, and there is some disagreement as to which attains the greatest length. The fish tapeworm gets to be sixty feet long, and the beef tapeworm has been reported to grow to as much as a hundred feet. . . .

Shellfish are creatures such as clams, mussels, oysters, and scallops that have a shell about their bodies. The octopus and squid are also included within the shellfish group, although their shells are either greatly reduced in size or are entirely absent. Several of these creatures easily qualify as giants of the animal world. The so-called giant squid, found off the coast of Newfoundland, is the largest of this group. Squids have ten arms or tentacles, two of which are much longer than the others. The largest of these squids actually measured, so far as could be determined, had an over-all length of fifty-five feet. The body was twenty feet long, while the longest of the tentacles measured thirty-five feet. It has been stated that pieces of squid tentacles have been found that were two feet in diameter. If this be true, such monster squids must measure a hundred feet in length when alive. A large squid would certainly weigh more than a ton, and although certain worms and jellyfish may be longer, the giant squid is considered the bulkiest of the creatures without a backbone. The octopus, a relative of the squid, may also be sizable. One with a tentacle span of twenty-eight feet has been measured; while off the coast of Australia they are reported to attain a diameter of forty feet.

Most of us have probably eaten clam chowder that was so diluted that we wondered if it had ever seen a clam. Such problems would not arise if cooks had routine access to an occasional inidividual of the giant clam of the Pacific. One of these creatures could be used to make clam chowder for an

army, while the shells may measure as much as three feet across. The American Museum of Natural History has a pair of the largest shells on public exhibition. Together they weigh 579 pounds. . . .

Huge spiders that catch birds are known with a leg-spread of over eight inches, and venomous tropical centipedes nearly a foot in length have been reported. Insects must also come in for their share of attention. The longest insect hails from Borneo and belongs to the group known as walking sticks. One of the largest actually measured was thirteen inches long. One would be tempted to use a shotgun in hunting some of the Australian moths. The Hercules or Atlas moth may have a wingspread of twelve to fourteen inches. . . .

Large fish are of interest to everyone, especially to fishermen who take great pride in the size of their catch. Unfortunately, the largest of the fish will probably never be caught on a hook. This fish is a kind of shark called the whale shark because of its large size. One of these fish forty-five feet long has been measured, and another was estimated to weigh over 26,000 pounds. This fish is comparatively rare and only a few large individuals have been captured, but competent authorities have estimated that the largest individuals may reach sixty feet or more in length. The food that this shark eats is one reason fishermen are not likely to catch one of these monsters on a hook. Despite their large size, they feed upon some of the tiniest creatures in the ocean, such as small fishes and squids. The chances are that they would not be attracted by large hunks of meat that are sometimes used as bait for other sharks. The whale shark could not eat a man even if it wanted to. The teeth are less than a half inch long, and the throat is quite small.

Other large fish and their reported sizes include the basking shark, which may measure some thirty feet and weigh nearly 10,000 pounds, and the sawfish, so-called because it has a snout with sawlike teeth along the edge. The well-known English biologist, Dr. J. Arthur Thompson, published a photograph of a sawfish in *The New Natural History* which he stated was twenty-nine feet long and weighed 4,500 pounds . . .

The size of large snakes has probably been exaggerated more than that of any other animal. Many people think that some

grow to be fifty to sixty feet long. Most biologists believe that the longest of the snakes is the regal python found in parts of Asia and adjacent regions. There is one authentic record of a 33-foot regal python, and this is the greatest length officially recognized for any serpent. On the other hand, the anaconda, a large water snake of South America, is certainly a competitor, and it might very well be the champ. A short time ago, I received a letter from a man now living in Canada who had done considerable exploring in Brazil many years ago. He stated that in 1924 he had killed an anaconda that measured 12.93 meters, or approximately 42 feet in length. . . .

Anyone interested in the size of crocodiles will certainly have seen old measurements of as much as thirty feet reported. Large crocodiles were certainly more common many years ago, but even optimistic biologists do not believe that they grew to be thirty feet long even in the heyday of their existence. According to Dr. Karl Schmidt of the Chicago Natural History Museum, the longest verified record for a crocodile is twenty-two feet, four inches. . . .

Everyone agrees that the ostrich is the largest living bird. A full-grown male may be eight feet tall and weigh more than 300 pounds. But authorities are not as much in agreement as to which bird has the greatest wingspread. The two chief competitors are the South American condor and a sea bird, the wandering albatross. The wingspread of both these birds has certainly been exaggerated, and a late edition of a well-known encyclopedia even states that the albatross may have a wingspread of seventeen to eighteen feet. The greatest verified wingspread for the albatross is eleven feet, four inches, and this is the largest of several hundred birds measured by different men. The largest condor that I can vouch for as having actually been measured had a wingspread of slightly more than ten feet.

The sulphur-bottom or blue whale is the largest of the mammals. In fact, so far as is known, this creature is the largest animal that ever lived. Several whales of more than 100 feet long are on record, while large specimens may weigh more than 300,000 pounds. An 89-foot whale, weighed aboard ship, piece by piece, was recently found to weigh approximately 300,707 pounds.

Elephants, well known to circus goers and favorites with children of all ages, are the largest of land-dwelling mammals. There are two different kinds of elephants, the African and the Asiatic. Asiatic elephants are most often seen in circuses, but the African variety attains the largest size. Certainly the most famous elephant ever exhibited was Jumbo, an African elephant that toured the country with a circus many years ago. Surprisingly, scientists were never able to get exact measurements of Jumbo before his death. According to one report, the late Dr. William T. Hornaday, former director of the New York Zoölogical Park, once requested permission to measure Jumbo. His request was turned down flatly by one of the outraged owners of the circus. However, we can be fairly sure the elephant stood about eleven and a half feet at the shoulder. Several wild African elephants over eleven feet have been killed, and at least two have topped twelve feet. The largest of these had a shoulder height of twelve feet, four inches. The difficulties of weighing a wild elephant, far from civilization, can well be imagined, but several in zoölogical parks have been weighed. One of the largest was an African elephant at the New York Zoölogical Park. It had a shoulder height of ten feet, ten inches and weighed 10,390 pounds.

Large horns and teeth are of sufficient general interest to be mentioned briefly. The Indian buffalo produces the longest horns of any known animal. A single horn in the British Museum is approximately six and a half feet long. Some of the wild Asiatic sheep, the famous *Ovis poli* and relatives, have done almost as well. The record here is six feet, three inches. The antlers of a moose cannot compete in length with the horns of either the buffalo or the sheep. On the other hand, the Alaska moose does produce the heaviest horns known. A pair of large moose antlers may weigh as much as 85 pounds.

The tusks of elephants are modified teeth, and the African elephant holds the prize for having grown the largest tooth of any living animal. The largest known pair, now in the British Museum, are from an old bull killed near Kilimanjaro in 1898. Each tusk exceeds twelve feet, and the pair are said to weigh 460 pounds. The imperial mammoth, an extinct relative of the elephant, somewhat exceeded these measurements in tusk

length. One of these tusks, now on exhibition at the American Museum of Natural History, is slightly more than sixteen feet long. Skeletons of the imperial mammoth that have been recovered show that in life some of these creatures were probably fifteen or sixteen feet high.

Of course, we have nothing as large as the imperial mammoths on earth today, and some of the extinct dinosaurs were even larger. On the other hand, we must not forget that the sulphur-bottom whale, still very much alive, is the largest animal that ever lived. So we need not believe that the world has become a dull place to look around in.

5. Man

LOREN C. EISELEY

The Fire Apes

When man gets to wondering how he became lord of the earth, his inclination these days is to search in some far-off place for the fossilized remains of his ancestors. Thus he hopes to learn the steps by which he changed from what he was to what he is. This is interesting and important. But more interesting is the question, how come it was *man* that became lord of the earth?

In a fascinating article written some years ago, Dr. Loren C. Eiseley, the University of Pennsylvania anthropologist, provides an answer. Man, he points out, got where he is by moving into a vacuum. When he came out of the trees and learned to speak and use tools, there were no tool-using animals already there to bar the way. If there had been, man would have been knocked off, and *they* would have been where we are now. In short, man is not really unique; he was merely the first to occupy the "cultural corridor."

Indeed, a second creature may have tried to enter the "cultural corridor": *Australopithecus*, the four-and-a-half-foot-tall hominid that once lived in South Africa. Australopithecus was not a man. But he was not an ape either; he had tools made from bone and stone, and he appears to have experimented with fire (if he did not use it regularly). And he appeared on the scene after the arrival of man.

What happened to Australopithecus? Was he wiped out by the first tool-using animal, man? We may never know.

Dr. Eiseley's article is reprinted, with his permission, from *Harper's Magazine* for September, 1949.

I was the only man in the world who saw him do it. Everybody else was hurrying. Everybody else around that hospital was busy, or flat on his back and beyond seeing. I had a smashed ankle and was using a crutch, so I couldn't hurry. That was the only reason I was on the grounds and allowed to sit on a bench. If it hadn't been for that I would have missed it. I saw what it meant, too. I had the perspective, you see, and the time to think about it. In the end I hardly knew whether to be glad or sorry, but it was a frightening experience, perhaps not so much frightening as weird because I suddenly and preternaturally saw very close to the end—the end of all of us—and it happened because of that squirrel.

The bird-feeding station stood on the lawn before my bench. Whoever had erected it was a bird-lover, not a squirrel enthusiast, that much was certain. It was on top of a section of thin pipe stuck upright in the ground, and over the end of the pipe half of a bread can had been inverted. The thin, smooth pipe and the bread can were to keep squirrels from the little wooden platform and roof where the birds congregated to feed. The feeding platform was attached just above the tin shield that protected it from the squirrels. I could see that considerable thought had gone into the production of this apparatus and that it was carefully placed so that no squirrel could spring across from a nearby tree.

In the space of the morning I watched five squirrels lope easily across the lawn and try their wits on the puzzle. It was clear that they knew the bread was there—the problem was to reach it. Five squirrels in succession clawed their way up the thin pipe only to discover they were foiled by the tin umbrella around which they could not pass. Each squirrel in turn slid slowly and protestingly back to earth, flinched at my distant chuckle, and went away with a careful appearance of total disinterest that preserved his dignity.

There was a sixth squirrel that came after a time, but I was bored by then, and only half watching. God knows how many things a man misses by becoming smug and assuming that matters will take their natural course. I almost drowsed enough to miss it, and if I had, I might have gone away from there still believing in the fixity of species, or the inviolability of the hu-

man plane of existence. I might even have died believing some cross anthropocentric dogma about the uniqueness of the human brain.

As it was, I had just one sleepy eye half open, and it was through that that I saw the end of humanity. It was really a very little episode, and if it hadn't been for the squirrel I wouldn't have seen it at all. The thing was: he stopped to think. He stopped right there at the bottom of the pole and looked up and I knew he was thinking. Then he went up.

He went up with a bound that swayed the thin pipe slightly and teetered the loose shield. In practically the next second he had caught the tilted rim of the shield with an outstretched paw, flicked his body on to and over it, and was sitting on the platform where only birds were supposed to be. He dined well there and daintily, and went away in due time in the neat quick fashion by which he had arrived. I clucked at him and he stopped a moment in his leisurely sweep over the grass, holding up one paw and looking at me with the small shrewd glance of the wood people. There are times now when I think it was a momentous meeting and that for just a second in that sunlit glade, the present and the future measured each other, half conscious in some strange way of their destinies. Then he was loping away with the autumn sunlight flickering on his fur, to a tree where I could not follow him. I turned away and limped back to the shadow of my bench.

"He's a smart squirrel, all right," I tried to reassure myself. "He's a super-smart squirrel, but just the same he's only a squirrel. Besides, there are monkeys that can solve better problems than that. A nice bit of natural history, an insight into a one-ounce brain at its best, but what's the significance of—"

It was just then I got it. The chill that had been slowly crawling up my back as I faced that squirrel. You have to remember what I said about perspective. I have been steeped in geological eras; my mind is filled with the osseous debris of a hundred graveyards. Up till now I had dealt with the past. I was one of the planet's undisputed masters. But that squirrel had busy fingers. He was loping away from me into the future.

The chill came with the pictures, and those pictures rose dim and vast, as though evoked from my subconscious memory by

that small uplifted paw. They were not pleasant pictures. They had to do with times far off and alien. There was one, I remember, of gasping amphibian heads on the shores of marshes, with all about them the birdless silence of a land into which no vertebrate life had ever penetrated because it could not leave the water. There was another in which great brainless monsters bellowed in the steaming hollows of a fern forest, while tiny wraith-like mammals eyed them from the underbrush. There was a vast lonely stretch of air, through which occasionally skittered the ill-aimed flight of lizard-like birds. And finally there was a small gibbon-like primate teetering along through a great open parkland, upright on his two hind feet. Once he turned, and I seemed to see something familiar about him, but he passed into the shade.

There were more pictures, but always they seemed to depict great empty corridors, corridors in the sense of a planet's spaces, first empty and then filled with life. Always along those corridors as they filled, were eager watchers, watching from the leaves, watching from the grasses, watching from the woods' edge. Sometimes the watchers ventured out a little way and retreated. Sometimes they emerged and strange changes overtook the corridor.

It was somewhere there at the last on the edge of a dying city that I thought I recognized my squirrel. He was farther out of the woods now, bolder, and a bit more insolent, but he was still a squirrel. The city was dying, that was plain, but the cause was undiscernible. I saw with a slight shock that nothing seemed very important about it. It was dying slowly, in the length of centuries, and all about it the little eyes under the leaves were closing in. It was then that I understood, finally, and no longer felt particularly glad or sorry. The city was forfeit to those little shining brains at the woods' edge. I knew how long they had waited. And we, too, had been at the woods' edge in our time. We could afford to go now. Our vast intellectual corridor might stretch empty for a million years. It did not matter. My squirrel would attend to it. And if not he, then the wood rats. They were all there waiting under the leaves.

II

I suppose everyone keeps by his night light some collection of tales by which he may frighten himself back to sleep in moments of insomnia. I know that I do. And if you are like me, you have, on occasional midnights, disputed lordship of the planet with intellectual octopi, or seen mankind pushed horribly aside by giant termites. These notions may be sinister at midnight, but the truths of daylight are simpler and more terrible: mankind may perish without assistance from any of these.

The human brain was a beautiful and terrible invention. It is unique. And because it is unique there are many who believe that its achievements will never be possible of duplication in nature, that, in the words of one naturalist, "progress hangs on but a single thread. That thread is the human germ plasm." A French scholar murmurs a little uneasily "man alone in the universe is not finished." Julian Huxley defends the uniqueness of the human species with an impassioned vigor. "Among the actual inhabitants of the earth," he says, "past and present, no other lines could have been taken which would have produced speech and conceptual thought. . . . It could not have been evolved on earth except in man."

That remark is both wise, in a sense, and foolish. It is the statement of a man who has looked far into the depths of the past and seen nothing so wonderful as man. Yet it betrays also the reluctance of the human imagination as it turns toward the future—its concern with itself, its unwillingness to relinquish the stage. This genuinely profound mind is surely not unaware that an intellectual dinosaur of the dying Cretaceous might well have murmured: "The saurians alone are not finished. What possible things could improve upon us?" The Cretaceous date line would have made it a wise and Huxleyian statement. It would have taken ten million years to force its serious alteration. Mr. Huxley is equally safe from refutation, so safe in fact that he sniffs contemptuously at the potential threat offered by our rowdy remaining cousins up in the family tree. "The monkeys," he says, "have quite left behind them that more generalized stage from which a conscious thinking creature could develop."

I am afraid that we are altogether too impressed by the fact that we live on the ground and that our remaining relatives, poor fellows, show a decided preference for trees. It never seems to occur to us that if they didn't stay up there we would jolly well show them what for. As for that "more generalized stage" which Mr. Huxley demands for the appearance of a thinking creature, I am quite sure that he cannot define it in a way which would seriously threaten the reputation of several existing primates.

The only way to become a "generalized stage" is to produce, in the course of time, several divergent smart descendants. No one can say that that faculty has been lost, but the whole monkey group will stay upstairs now till we are gone. And if they don't come down, there is still my squirrel, whose actions at times remind me of a certain ancient human forerunner in the Eocene. That chap wasn't recognized as "generalized" either, until somewhere along the way he began to walk on his hind feet. In the beginning, I'm not at all sure he was as smart as my squirrel.

Now I have said that Mr. Huxley is safe from refutation, geological time being what it is. If it is impossible to refute him until the passage of another sixty million years, it might be more comfortable to assume he has spoken the truth. It might have been, that is, up until last year. It was then that scientists began to scratch actively in the African bone lands. It was then that archeologists began to whisper behind their hands and exchange glances. It concerned, of course, a certain skull. That in itself was bad enough, but what ensued was worse.

He was an ape, they had said in the beginning: "A creature lacking the distinctive temporal expansions which appear to be concomitant with and necessary to articulate man is no true man." Then there had come that frightening insistence on the part of his discoverer that he had used fire and tools.

The little fellow was promptly redescribed. His type was cited in glowing terms as "intelligent, energetic, erect, and delicately proportioned little people." He was credited with speech, and spoken of respectfully as a potential human ancestor. It was more comfortable that way. Otherwise you were confronted with a spectacle like Dunsany's mysterious Abu Laheeb, that

strange being squatting over its lonely fire in the marshes—the only beast in the world that made fire like man.

The mythical Abu Laheeb survived by hiding in the papyrus swamps of the upper Nile. *Australopithecus Prometheus,* the ape who made fire, was not that fortunate. He disappeared. The reason why concerns Mr. Huxley's philosophy and is in some sense a refutation of it. Men say, in the books, that man is the last hope of life on the planet, the last chance, that is, for brain. In the past, however, when man was yet weak, a cousin tried to take the path he walked upon and almost succeeded. A cousin from the despised roof tree, where the eyes still watch us overhead.

To explain his failure and near success, we must go back millions of years. To explain what will come after our own extinction, we must again read backward—not for biological events which can never be repeated in exactitude, not for signs of the reappearance of forms which have had their day and will never again emerge into the light—but rather to project forward into the future those dread principles which have controlled the movement of life on this planet through untold eons of time, and which will continue to direct its destiny through the untold eons of the future. The destructiveness of man has lent a sparse and impoverished aspect to the animal life of the present day. It implies senescence and decline. Both are illusory. The great life stream awaits only its opportunity—the moment of human disappearance.

III

There are two sorts of evolutionary movement in the world of life, and one is more mysterious than the other. There are, for example, the slight differences which arise between species, the multiplicity of closely related shrubs, grasses, trees, and animals which can be observed over an acre of ground. All of these forms, plant and animal alike, may be occupying essentially the same environment or small, slightly divergent "micro-environments" within that acre. The diversity is pleasing. It leads us to comment on the infinite richness of life. Much of this burgeoning splendor is, nevertheless, without meaning so

far as the grander progression of life is concerned. Some of it is the product of genetic drift which may have little importance even in terms of natural selection. It is diversity without significance, save as it represents the infinite capacities of the cell.

The real mystery, by contrast, lies on a mightier stage. It is the great symphonic movement through the world of the corridors. It is the fish who crawled ashore on his fins, the amphibian who painfully learned to walk. It is the reptile who invented the egg and thus released land vertebrates from dependence on the water. It is the saurian who flew, and who also learned to control his body temperature until he became a high-speed efficient mammalian machine whose brain did not grow torpid in the chilling night. It includes, also, a creature who came down from the trees and took his first tentative step down the long grassland corridor that was to lead him out into the magnificent vistas of conceptual thought.

The advance into those various worlds, into the air and the light out of the depths of the waters consumed millions of years of effort. It was not all an upward movement. Species by thousands died; species went into the ground; species went back to the waters; species clung to the high trees and shrieked down at their human brothers. The smaller movements we understand well—the horse from four toes to one, the age-by-age growth of horns on Triceratops or the titanotheres.

Instead it is the plunge through the forbidden zones that catches the heart with its sheer audacity. In the history of life there have been few such episodes. It is that which makes us lonely. We have entered a new corridor, the cultural corridor. There has been nothing here before us. In it we are utterly alone. In it we are appallingly unique. We look at each other and say, "It can never be done again." It is almost as though in our very bones were felt ancestral memories of the way we have come, and the feeling like magic touches us once more so that we repeat with something like terror in our voices, "It can never be done again."

Now it is one of the strange paradoxes of biology that this feeling of mystery concerning the great biological inventions which have opened the doorways of life has deepened as our knowledge has increased. Long evolutionary lines in a given

environmental zone have been worked out, transition forms have been noted, and many sequences leading by imperceptible degrees from one form to another have been observed. In the beginning, Darwin and his followers assumed confidently that the major gaps which yawned between the phyla—the space, say, between the fish and the amphibian, between the reptile and the bird—would eventually be found to contain transition forms extending in the same imperceptible way from the one form to the other even though a major life threshold had been crossed.

The lack of such transitional forms was not at first disturbing. Success in the pursuit of ancestral lines over long time-intervals led to the conclusion that these major gaps were due solely to imperfections in the geological record; that the book of nature had, so to speak, missing pages, but that the main outlines of the story could easily be read from the pages that remained. It was not until much later that those missing pages were observed to occur with almost monotonous regularity at some dramatic transition point, involving the emergence of a new form of life and its adaptation to either an unentered corridor or a corridor offering possibilities of being intruded upon in some new way. The new type, in other words, seemed to emerge with astounding quickness, considering the generally slow evolutionary pace to be read from many of the remains which the fossil hunters were discovering in the better known strata of the earth.

This situation has led to much speculation. It has led on the part of some to a denial of the reality of evolution, on the part of others to claims for some type of "jumping evolution" in which fantastically complex mutations brought new organic forms into existence at a single step. The confusion created by this situation is perhaps nowhere better expressed than in Lecomte du Noüy's recent book, *The Road to Reason*. He says: "The general fact that paleontology only shows us a few transitional forms and still fewer really primitive forms, is also very disturbing. . . . We do not grasp the origin of any group."

It happens, however, that these widely expressed doubts are often tinged unconsciously with emotionalism. The gaps exist but isolated discoveries reveal that transitional forms are by no

means non-existent. They are merely scarce. We have in growing numbers the mammal-like reptiles standing between the reptiles and the mammals. We have a strange, rare creature, Archaeopteryx, lying between the reptiles and the birds. There are other gaps which remain unclosed. These signs are, nevertheless, suggestive. More fossils will be found. Those which we possess, inadequate though they are, do not support the notion of fantastic leaps in nature.

They suggest, instead, that the march across each major barrier into a new sphere of existence is made rapidly if it is made successfully at all. A basic organic change of this nature is estimated by the brilliant modern student, G. G. Simpson, to have proceeded at a pace, in some instances, ten or fifteen times more rapid than the later recorded evolution of a given group after it has begun to exploit its new domain. The comparatively hasty crossing, hasty in a geological sense, was made by small groups of animals undergoing extreme selection pressure. As a consequence, there will never be numerous fossils. Archaeopteryx, the bird-reptile, for example, was found in 1861. It still remains a solitary specimen.

Another fact can be noted as we study these records. It is in a sense obvious, yet it has been neglected by many writers obsessed with human uniqueness or with the superiority of the mammalian line in general. It can be laid down almost as a truism. *No successful crossing into a new corridor of life can be effected if that corridor is completely dominated by prior intruders.*

This statement must be made somewhat dogmatically. Apparent exceptions can be observed, but they constitute special cases which do not affect the general principle. It could be noted, for example, that the reptiles made two separate attempts to conquer the air corridor, once by the use of membranous wings—the giant glider Pteranodon being a popularly known example—and secondly by the evolution of true wings and feathers. Both attempts were successful for a long period, and both must have competed for a time. Eventually the Pterosaurs disappeared and left the corridor to the birds.

Two facts explain this rather unusual situation. Both forms apparently got across into the airways at approximately the

same time, so that neither one had radiated and adapted sufficiently to exclude the other. In addition, the development of flowering plants with accompanying nutritious seeds in the Cretaceous period profoundly stimulated insect evolution. The nutritive possibilities in the air corridor thus increased, but increased in a direction which favored the smaller, speedier, and more effective mechanism, namely, the birds.

From the Cretaceous to the present the birds have dominated the airways, and the smaller environmental niches within the airways, so effectively that no other vertebrate has successfully challenged their control. One other animal, it is true, has evolved true flight in the interim, but its position only reveals the reality of our truism. The bats, true mammals, came late to the scene. They made the crossing, but made it surreptitiously in the evening twilight. The vast majority of birds are diurnal. The bats cling to the edge of evening, and such prey as they can find there. Their numbers, in comparison with birds, are scant. Both figuratively and literally, they are creatures of the twilight, dwellers at the unwanted margin. That is why they survive.

What the bats might have been capable of under other circumstances, it is, of course, impossible to conjecture; but the tremendous energies, the unknown capacities which may be held in check while a new form of life surges endlessly against an already closed corridor, is nowhere better illustrated than in the story of the rise of the mammalian world itself. Our interpretation of that rise is apt to be distinctly colored. We think of dinosaurs as great brainless beasts which failed in the struggle for life, and we think of the mammals, our own ancestral line, as a highly effective group which crowded the reptiles aside. Nothing, in actuality, could be further from the truth.

I remarked on an earlier page that the truths of daylight are often the most terrible, and that the end of the human story does not demand our extermination at the hands of some more intellectual or fantastic form of life. That statement was deliberate. The reptiles are a prime example. For 140 million years, during that period known as the Mesozoic, they were the undisputed masters of this planet. In enormous numbers they radiated into every possible geographic niche. They swam and

they flew and they walked. Brainless or not, they survived a period of time far more extended than the life of man, far more extended than the whole Age of Mammals.

Now what is not very generally understood by the lay public is the fact that throughout the greater portion of this 140 million years the mammalian world was in existence. It was in existence, but it was highly inconspicuous. It was small; it hid under bushes; it concealed itself in trees. It had no giant representatives such as it developed later on after the disappearance of the reptiles. Like the bats on the edge of the bird world, it was existing on tolerance. It was marginal. To have grown larger would have been to invite the attention of the most formidable carnivores the world has ever seen—perfected killing machines with teeth like bear traps.

For a hundred million years those little mammals waited. No one would have dreamed that they, in their turn, might create monsters, and no one, above all, would have imagined that the gray and infinitely complex convolutions of the human brain were locked away in the forebrain of an insectivorous creature no larger than a rat. An observer waiting for some sign of creative emergence among those little animals in the underbrush would have grown weary as years by the million flowed away. He would have sworn that every variation in the game of life had been exploited and played out—that the reptiles were the master form—that the mammals were effective only upon an infinitely small size level.

Yet in the end, that strange end that closed the day of the Ruling Reptiles, the armored giants vanished. They vanished from the seas and the fern forests; their great gliding wings disappeared from the coastal air. Nothing living, so far as we can determine today, threatened them. The mammals were insignificant, envious eyes in the reeds—that was all. We in this remote age may murmur about climatic change or any one of a dozen vague possibilities. Sometimes we consider the notion that species may run through a lifetime, grow old and die, as does an individual organism. We do not know. But this we are unpleasantly aware of: the armored ones went in daylight. Nothing, not even their successors, thrust them aside. It would be millions of years before the shovel heads of the mammalian

titanotheres grazed in the valleys that knew the thunder lizard, Triceratops.

The mammals did not destroy the great reptiles; they simply occupied, long after, an empty throne. It was only then that the suppression of creative energy burst forth in a second marvelous efflorescence, the radiation that created the mammalian world. The story, however, has a moral that is little read: man also is the master of a corridor; there is nothing visible to compete with him. He has destroyed the great mammals and left only the little eyes under the rosebush in the garden. He is safe now to write books about his unique qualities—and he is unique, as unique as the dinosaurs. He will not be menaced from the field's edge, but the eyes are still waiting. Once they waited a hundred million years. They can do so again.

This time it will be a new corridor—the cultural corridor—that they enter, but it will not be as unique as it seems to us, writing as we do that we are the "sole representative of life in its progressive aspect and its sole trustee for any progress in the future."

Once, long ago in Africa, that cousin of whom I spoke made tools and, some think, may have experimented with the forbidden magic of fire itself. Small and timid and slight of brain, he fades back into the silences of pre-history. He made the crossing at the wrong moment, but he proved we are not so unique as we imagine, that the crossing can be made again, perhaps even from above, out of the old rooftree, where everyone sits with his tail curled safely out of reach.

It is the safety of trees or the safety of being men now. The line is sharp; there is no halfway mark as there was when the first ill-adjusted migrants stumbled into an empty world. There is no longer any room for an ape who lights fires and is not a man.

IV

Almost everything about this animal, up until recently, has been controversial except the fact that it existed. It has been called an ape. It has been called a man. It has been said to have walked upright. It has been said that this is untrue. It has been

claimed that it spoke. It is said not to have spoken.

More complete specimens have lately begun to fall into the hands of the bone hunters, so that some of the questions which tormented earlier workers have been answered. Others, however, have taken their place.

The Australopithecine man-apes of South Africa are a group of small, upright-walking anthropoids who haunted the grasslands of the Vaal River area from five hundred thousand to a million years ago. They are not all alike in detail, but the whole stock is characterized by teeth of a quite human character. The great shearing canines of the existing apes are reduced to human proportions. These animals must have been omnivorous grassland wanderers, pursuing small animals, eating wild seeds, and probably robbing an occasional bird's nest. Around four feet in height, with a brain ranging from 450 to 650 cubic centimeters, their intellectual capacities, though low by human standards, were undoubtedly superior to those of any existing gorilla or chimpanzee.

They are the only grassland bipedal ape, as contrasted with primitive grassland man, of which we have any knowledge. As I pointed out earlier, they have been called apes. More lately there has been a tendency to call them men. Awkwardly enough, however, such datings as we have been able to compute for them are much too late in time to allow for their being the direct ancestors of true men. Some, at least, of the man-apes were the contemporaries, for a brief while, of primitive men.

I suppose that, if the truth were known, one reason why man is so impressed with his own uniqueness is the fact he is alone today in the grassland corridor. In a few remote parts of Africa, a scant number of lower monkeys venture into waste spaces on the ground. The baboon is one of them. His experiment has turned in another direction. His face is doglike. He runs upon all fours.

Of that series of arboreal experimenters who ventured into the first grasslands of the planet during the Miocene epoch and who teetered diffidently from one tree clump to another, upright on their two hind feet, man alone remains. The grasslands were too open, competition too fierce as the sub-men multiplied, for the long continued survival of unlike forms. We of today see

a yawning gulf between ourselves and the old forms in the trees. On the grass the others have vanished. The corridor is filled and the rifle would eliminate any wavering half-soul from the forest twilight who was so rash as to venture among us. It is too late for the crossing, too late until man is gone.

I suppose it is the illusion of uniqueness which for so long caused the student of human evolution to take a scattered series of human fossils and try to arrange them in a single line of ascent leading to modern man. It is still being tried with the new man-apes, but there are two embarrassments: their relative recency, and the diversity of their species. It is simply not possible that they are all on the main line of ascent to ourselves. That the Australopithecines have vanished while many simple arboreal relatives of ours survive is not surprising. The man-apes tried to occupy the same environmental niche as man, and as a consequence man destroyed them.

This does not mean that the Autralopithecines are totally unrelated to ourselves. It does mean, however, that the old notion involving one human ancestral form and one only as taking the momentous step of climbing out of the trees and learning to walk upright—thus starting a simple and direct evolutionary movement which culminated in man of today—is a fantastic simplification of events.

Twenty million years ago the grasslands of the world were spreading. The long cooling that was to produce the Ice Age of later times had just begun. The low continents of the age of reptiles were giving way to mountain growths that swung the ancient jungles of the earlier lands far skyward, and brought drought to the inner continental basins. The grasslands spread farther and farther. Over vast areas the jungle disappeared or shrank to parkland.

We know that among the mammals of this period, many diverse orders turned to a grazing existence. Changes in their teeth tell us as much, for the high silica content of grass forces the development of a specialized grazing dentition which will resist wear. Man, of course, is not a grazer, nor were his forerunners up in the diminishing branches.

That grassland world was, nevertheless, attractive. More and more animals were moving into it; here and there in the park-

lands, anthropoid apes of forms little known ventured on to the ground. A little like the archaic living gibbon, they may have scurried on their hind feet between isolated clumps of trees, snatching insects and seeds before swinging safely into the branches again. The slow changes that some of these animals were undergoing in habits and foot structure may have taken millions of years.

There must have been many of these apes on the edge of the grasslands. We need not be surprised if more than one type, over the vast Old World land mass, successfully made that crossing. The corridor was open to aggressive, lively anthropoids who were willing to hunt small animals and insects, and whose diet was unspecialized. The climate was more healthful than that of the parasite-infested jungles. A strange competition began.

It was the competition of an odd lot of animals, the apes of the grassland, uncertainly erect, but with the neurological preference for that posture already developed among the branches of the forest. It was the competition of social animals, and therefore it was the competition of groups. Out of that struggle for food, for mates, and for life, the best adapted, the most clever brained, the most successfully communicative would survive.

I say communicative because somewhere here on the grasslands in an environment infinitely more demanding and dangerous that the safe retreat of the trees, the already extensive but instinctive call range of the old tree world began to be abandoned for conceptual thought and speech. Under mysterious endocrine influences about which we know nothing, man's infancy was becoming prolonged, his brain a plastic thing upon which incipient society was beginning to mark the folkways of the group. The strangest corridor in the history of life on this planet was being entered—the cultural corridor. Its final possessors would be masters of the earth. They would write books. They would describe themselves as unique. They were not.

V

The first of those peculiar human-footed apes to which we have previously referred, was announced to an incredulous world by Professor Raymond Dart in 1924. It took over twenty years to discover more of them and to learn something of their habits. Because it was not believed, at first, that they spoke or made tools, Dart, in spite of his conviction that they were closely associated with the earlier history of the human line, referred to them as "no true men."

This year, at Makapansgat in the Central Transvaal of South Africa, Dart reported Australopithecus Prometheus, the fire-maker. Reporters, of course, went wild. Scientists scratched their heads and looked dubiously at one another. The new fossil was reported from deposits showing evidence of the use of fire in the shape of charred bone and traces of charcoal. Though no stone weapons were discovered, there were suspicious indications that Prometheus had used the long bones of slain animals as clubs. A series of neatly fractured baboon skulls from which the brain had probably been extracted for food supplied the evidence.

A very simple tool-using capacity on the part of an animal with a 650 cubic centimeter brain capacity is acceptable. That these creatures may have been fire-users has shaken all our established notions of human culture history. The suspicion continues to be entertained in some quarters, and will continue until further reports are available, that perhaps advanced forms of man may be responsible for the fires and the broken cranial case of Prometheus himself. It is known, at least, that there are somewhat later humanly occupied caves at Makapan. It must not be forgotten, however, that it was Dr. Dart who recognized, over twenty years ago, the importance of the first Australopithecine cranium; it was conservative science that smiled and later had to eat its words.

Whether or not the human-footed apes were fire-users, we know that the animal remains with which they are associated at Makapan place them well within Early Ice Age times. Human relatives they are, but in the narrow sense, at least, they are not men. Men, low-browed, perhaps, but true men, were already in

existence. The man-apes, by contrast, are a part of that ancient bipedal horde which millions of years ago came out upon the grasslands. Less massive than their divergent human brothers, they clung to the fringe of the corridor, ran before its terrors, and shared with us that dark and ancient blood from the times before man.

Perhaps at the last, late, much too late, they lit the fires that might have made them man; perhaps even—and that in itself is a weird thought, since no animal alive has done it—they watched trembling behind a bush and learned from men the secret of the fire. Perhaps already in some dim, half-human way they sensed their world was fading. Theirs were the last furred hands and theirs the last half-animal voices to be seen and heard in the cultural corridor before the pathway backward closed forever. When it opens again we shall be gone.

Sometimes at night I think one can feel even the pressure of mice waiting in the walls of old houses. All that concentrated life around us and above us, held in check, surging impatiently, ready for a new experiment, tired of us, waiting our passing, active with the busy mysteries of the cell. Sometimes one catches oneself wondering what the fire-apes were intending when they crossed the barrier, whether they were cut short in a new experiment, something smaller, more delicate, more—something, but not a human something. Something for which human beings must first be gotten out of the way. It is perhaps significant that even we ourselves feel a growing inadequacy. Perhaps that is really the secret. Perhaps we are going away.

GEORGE GAMOW

Through the Blood Stream

Among the most remarkable creations of recent scientific literature is Cyril George Henry Tompkins, a bank clerk with an addiction to curious dreams. In one (recounted in *Mr. Tompkins in Wonderland*), he finds himself in a small, but expanding universe, where the time scale is rather more relative than usual. In another, he embarks on a series of adventures inside the atom and barely escapes annihilation (see *Mr. Tompkins Explores the Atom*). In a third (described in *Mr. Tompkins Learns the Facts of Life*), he tours his own insides. The start of the tour, a trip through his blood stream, is used by permission of Cambridge University Press, publishers of all three Mr. Tompkins books. The author is, of course, George Gamow, the witty physicist whose acquaintance we have already made in "The Origin and Evolution of the Universe." The drawings are adapted from Dr. Gamow's own drawings for the book.

The large waiting-room of the New Memorial Hospital was cool and comfortable. The patients were sitting in somewhat strained poses, waiting for their turn to be called for inspection. Some of them were trying to distract their thoughts by glancing through magazines, others were just staring blankly into space. Once in a while a stretcher rolled past, pushed by a white-clad attendant; everybody's eyes automatically followed the procession until it disappeared at the far end of the corridor.

Mr. Tompkins picked up the latest issue of *The New Yorker*, but the subtle humor of the cartoons, which he always enjoyed so much, did not seem to affect him now. Yesterday he had felt quite all right and full of life. But this morning, during breakfast, he had glanced through a newspaper account of a lecture on cancer. The article described in vivid words how the usually

regular and well co-ordinated processes of cell division in living tissues can sometimes get out of hand, producing ugly malignant growths, and leading ultimately to the complete destruction of the organism. The author had compared these destructive tendencies of certain aggressive cell groups, which appear now and then within the peaceful commonwealth of normal cells constituting a living organism, with similar phenomena in the field of sociology and world politics, and suggested that in both cases the only cure known at present is the use of the scalpel or the sword.

"Sure," agreed Mr. Tompkins, "to hell with all this appeasement business. *Si vis pacem, para bellum!*"

But when he got to the bank, thoughts about the grim possibility of aggressive cell division just would not leave his mind, and all the while, as he cashed checks, he felt that something unusual was going on in the organized community of cells which he called his body. His head was heavy, his respiratory organs seemed to work under unusual strain, and he felt an ache in all his joints.

As he had also completely lost his appetite, he decided to make use of the lunch hour for a visit to the dispensary of a large city hospital, which was fortunately just round the corner. He wanted to make sure that no aggressive cell groups were operating in *his* body. There was a long waiting line, so he picked up a magazine from the central table, and settled comfortably into the last vacant arm-chair. He felt quite relaxed now, and a few minutes later the magazine fell softly on to the marble floor at his foot.

Suddenly all the people in the waiting-room straightened in their seats, and turned their heads toward a tall man in a snow-white laboratory gown, who had just walked in through the door of an adjacent office. Mr. Tompkins knew this man very well indeed, through photographs which appeared now and then in the city's newspapers. It was the famous Dr. Streets, the world-renowned authority on abnormal cell growth. Noticing Mr. Tompkins, who was almost hidden from sight by an enormously fat lady sitting next to him, Dr. Streets rushed toward him with wide-open arms.

"Oh, my dear Mr. Tompkins, what in the world could have brought you here?"

This was very strange indeed, since, though Mr. Tompkins might well know of this famous figure of the medical world, Dr. Streets had no reason whatsoever to know Mr. Tompkins.

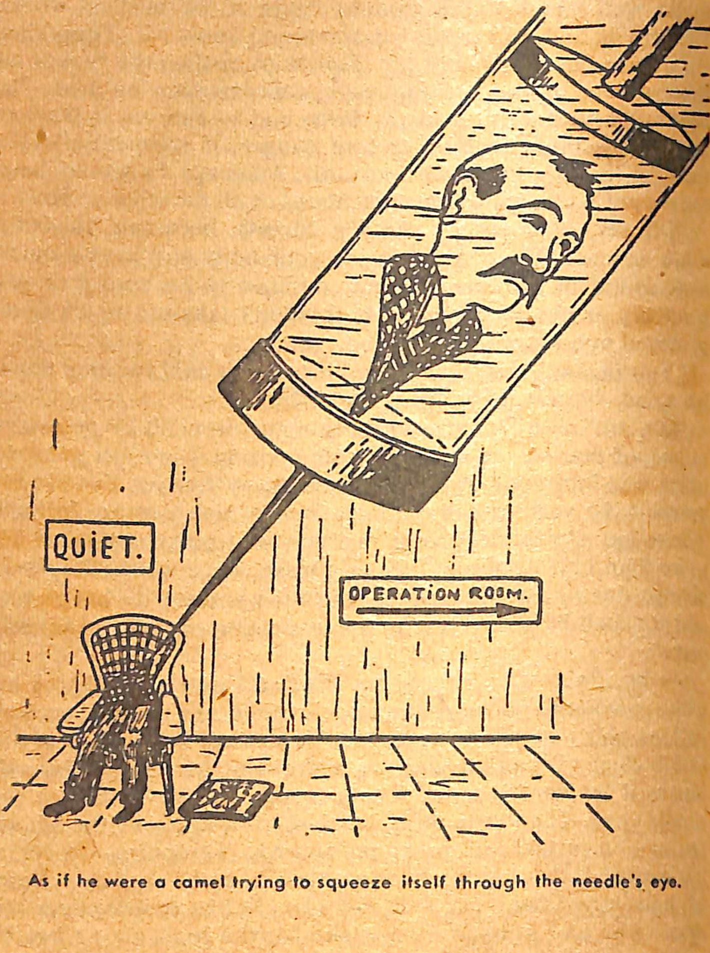
"I came here, sir," said Mr. Tompkins, feeling the eyes of all the patients in the waiting-room concentrating on him, "to check the mitosis rates in my cells, and to find out if there is any neoplasm formation or any danger of metastasis." (He thought that by using this scientific language he would have some excuse for being inspected ahead of all the other patients.)

"Oh yes, of course," said Dr. Streets, becoming suddenly quite serious. "We can get inside your body and have a quick look round at various cell communities to be sure they are behaving in the proper way. It shouldn't take too much time, provided one knows what to look for."

"You mean," said Mr. Tompkins with a chill running down his spine, "you want to open me up?"

"Oh, no," said Dr. Streets soothingly, "it won't be necessary unless, of course, we find something wrong. I am just going to inject you into your own blood stream, so that you can see for yourself the various cell colonies from which you are formed. The round trip through your main circulatory system takes not more than half a minute but, of course, since we shall have to change our linear dimensions, the time scale will change too, and we shall be able to make the inspection in quite a leisurely way."

As he spoke, Dr. Streets put his hand into a pocket of his white gown and, pulling out a large hypodermic syringe, pointed its long shiny needle toward Mr. Tompkins. There was a violent feeling of suction and for a moment Mr. Tompkins felt just as if he were a camel trying to squeeze itself through the needle's eye. Then something pinched his arm above the elbow, the suction turned into pressure, and Mr. Tompkins was forcibly ejected into a rapidly flowing mass of some slightly yellowish transparent fluid. For a moment he felt like an inexperienced diver, who had jumped by mistake from a high diving board, and was making desperate motions with his arms and legs to come to the surface. But, although this did not bring him any-



As if he were a camel trying to squeeze itself through the needle's eye.

where, he did not seem to feel any lack of air, and his lungs seemed to function quite normally.

"What a dirty trick," exclaimed Mr. Tompkins; "he must have turned me into a fish!"

"You don't need to be a fish," said a quiet voice near him, "to be able to breathe inside your own blood stream. After all, it carries all the oxygen supply needed for the respiration of your body cells. But if you feel uncomfortable floating in the plasma, why don't you climb up on one of the erythrocytes and have some rest. They are just as comfortable for travel as the proverbial flying carpet."

It is only now that Mr. Tompkins noticed a large number of lens- or bean-shaped bodies floating in the fluid stream. They were about three feet thick, some twenty feet in diameter, and seemed to be upholstered with bright red velvet. Climbing up on one of them with the help of the doctor, Mr. Tompkins felt that his miseries were over.

"Aren't these erythrocytes, as you call them, simply what are known as red blood cells?" he asked, stretching out on the soft velvety surface.

"Exactly so," was the answer, "in fact, *erythros* means 'red' in Greek. The material which gives them that bright red color is known as hemoglobin and is a complicated chemical substance possessing great affinity for oxygen. When the blood stream passes through the lungs, these red blood cells absorb large amounts of oxygen and carry it along to various cell-colonies in the body. In fact, although erythrocytes occupy less than fifty per cent of the blood fluid, they can absorb seventy-five times more oxygen than can possibly be dissolved in the plasma itself."

"Must be a tricky substance," said Mr. Tompkins thoughtfully.

"So it is," agreed Dr. Streets. "And, as a matter of fact, biochemists are still working hard to get its exact composition. So far, we have been able to untangle only one small part of this complicated molecule, a part known as hematin. If you use this lens, you can see how complicated its structure actually is."

"You mean I can see the separate atoms forming the molecule?" asked Mr. Tompkins with surprise.

"Sure you can. At our present scale you are just about two microns tall. That means that the atoms will look to you like little spheres a few tenths of a millimeter in diameter. A simple pocket-lens would be enough to see the structure quite easily. Just look at those little pimples covering the surface you are sitting on."

Taking the lens from the doctor's hand, and stretching out on his stomach, Mr. Tompkins concentrated his attention on a tight group of seventy-seven atoms forming a hematin molecule. It was a symmetrical structure built around a heavy atom of iron located in the very center. The iron atom was surrounded by a group of four nitrogens, and twenty carbons. Outside were attached hydrocarbon and carbohydrate groups sticking out in all directions, like the tentacles of an octopus. Caught in these tentacles like flies in a spider's web were numbers of oxygen molecules absorbed by the hematin.

"It's funny," said Mr. Tompkins, straining his eyes to see all the details, "I can see quite clearly the structure of the hematin molecule itself, but I can't make out anything of the larger body to which it is apparently attached."

"That is simply because you can't see in your dreams the things which have not yet been cleared up by regular scientific research," explained Dr. Streets. "The structure of hematin is known in detail through the work of the German biochemist, Hans Fischer, whereas the structure of the much larger protein molecule to which it is attached still represents one of the unsolved problems of the science of biology. I wouldn't mind having a look at it myself if my pocket-lens would show more than is known to science today."

The two men were so involved in their conversation that they did not notice that the broad stream through which they were previously floating, had narrowed into a small channel, and that their erythrocyte was gliding most of the time along its slippery semi-transparent walls.

"Here we are!" exclaimed Dr. Streets, looking around. "We have entered one of the small capillaries supplying the blood to the thumb of your left hand. These large lumps of protoplasm lining the walls of our capillary channel are the living cells of your own flesh."

"Oh!" said Mr. Tompkins who had already seen microphotographs of cellular structure, "they look exactly as they should. And, I suppose, the darkish bodies near their centers are the *nuclei?*"

"Right," replied the doctor. "And, speaking of cancer, you notice that these particular cells are quite normal. Cancerous cells are characterized by a special growth pattern, and in some cases by abnormally large nuclei, and can be easily distinguished under the microscope from normal healthy cells. The trouble is, of course, that in order to diagnose cancer in its early stages, one would have to examine millions of cells to be absolutely sure. But I hope that we shall soon be able to develop some method which would permit us to do so in a quick and inexpensive way."

"I see," said Mr. Tompkins, who had begun to feel a little short of breath, "I hope you will have such a method soon. But it seems a little stuffy here."

"Sure it does," retorted the doctor. "After all, the blood stream with which we are traveling comes here to give away its oxygen content to the cells, and to take carbon dioxide and carry it away from your body. Watch how the oxygen molecules are getting detached from the body of our erythrocyte and sticking to the walls of the capillary. They will then diffuse through these walls into the lymph (the liquid surrounding the individual cell), and then into the cells themselves. At the same time, the carbon dioxide accumulated in the cells is draining outwards into the blood stream where it is partly dissolved in the plasma, and partly attached to the molecules of the hemoglobin. So our trip back to the lungs is not going to be pleasant."

"I should say so," grumbled Mr. Tompkins, feeling his lungs nearly bursting. "Isn't it silly that I must almost suffocate in order to keep my own thumb breathing?"

He certainly did not feel too good, and black spots were floating before his eyes.

"Must be cellular nuclei," thought Mr. Tompkins. "Oh, no! It looks more like heads with sailors' caps on. Am I joining the Navy, or what?"

"Two hundred fathoms," said a husky voice from nowhere, "and still going down. D—— these jammed valves!"

"I hope they know about it at the Base," said another voice. "They'll surely do something about it."

"Oh yeah!" screamed somebody in semi-hysterics. "No, brother, there's no way out of Davy Jones's locker!"

Suddenly the body of the submarine was whirled round violently as if caught in a giant whirlpool. The people and the instruments were thrown about all through its narrow interior, and Mr. Tompkins found himself clinging to the base of the periscope. For a moment he saw the face of the doctor, a chalk-white face. . . .

"Hold on!" whispered the doctor, "we have just entered the *right ventricle* and are heading into the *pulmonary artery*. There will soon be enough air for everybody!"

When Mr. Tompkins again recovered consciousness, the air, or rather the plasma, was indeed quite clear. He was lying on the same erythrocyte tightly embracing the doctor's leg. Their erythrocyte was again floating smoothly through a rather narrow channel but there were no cells crowding the space on the other side of its transparent walls. On the contrary, it seemed quite empty except for swarms of what Mr. Tompkins first thought to be little flies or fleas, dashing through it in all directions.

"Atmospheric air," said Dr. Streets pointing with his long finger.

"You mean we are out of my system?" asked Mr. Tompkins hopefully.

"Oh, no," said the doctor, "we are still in your circulatory system, but we are now passing through one of the capillaries of your lung, to get rid of the carbon dioxide, and take in a new supply of oxygen. The free space across the wall of the capillary is called an *alveolus*, and is just one of the air pockets, or bays, which line the inside surface of the lung. Each time you breathe, the lung and all its alveoli are filled by the fresh air from the outside so that venous blood can get its new supply of oxygen."

"You mean that these tiny rushing insects are actually air molecules?" exclaimed Mr. Tompkins.

"That's it. But remember that in our present scale, which is roughly one in one million, simple molecules like those of oxygen or nitrogen are about one-tenth of a millimeter in diameter.

No wonder you mixed them up with fleas, especially considering their fast, dashing movements. See how many of them get through the walls of the capillary and attach themselves to the red blood corpuscles. By the time the blood finishes its passage through the lungs, and enters into the *aorta* it is ready again for the new trip across your body."

"I don't think I should like to make that journey again," said Mr. Tompkins, who had not yet recovered from his unpleasant experience.

"But you should!" retorted the doctor. "You haven't seen much yet, in fact you were delirious throughout most of the long trip from your thumb to the lungs. Besides I haven't yet had a chance to look into the question about which you came to me, and to diagnose your condition."

"All right," said Mr. Tompkins reluctantly, "but perhaps we can get hold of an auxiliary oxygen tank."

"We can do better than that," said the doctor, "as soon as conditions become really uncomfortable we'll simply get out of your system. But you'd better get ready for a rough ride now, as we are just going to enter your left heart."

"What do you mean: left heart?" exclaimed Mr. Tompkins, baffled. "I thought the heart is always on the left."

"That is correct, and I should rather have said left half of your heart. You probably do not know that the human heart, which is essentially a pump driving the blood through the body, is actually a double pump. The right half of the heart pumps the blood from the body into the lungs, whereas the left half pumps it from the lungs back into the body. Both pumps, complete with valves and so on, are quite independent, except that both are driven by the same muscles. Now hold on!"

Their erythrocyte was now behaving very much like a canoe riding the rapids of the Colorado River, and Mr. Tompkins had quite a difficult time trying not to be thrown off into swirling plasma. They rushed through a narrow opening into the left auricle (the entrance chamber of the heart) and then through another valve into the left ventricle itself. A second later the heart contracted, and their erythrocyte was forced out again through the exhaust valve of the heart pump.

"Well," said the doctor making himself comfortable on the

soft velvety surface, "now we can have a long chat about things. Is there anything in particular you would like to know?"

"I would like to know first of all," said Mr. Tompkins, "whether or not this thing we are riding on is alive?"

"It's a difficult question," said Dr. Streets. "The answer is probably yes, but with some reservations. The fact is that red blood corpuscles are constantly being born; they live through their life, and finally they die when they are three to four months old. The breeding place of erythrocytes is the red marrow of the bones, where they are produced by the steady regular division of special cells, known as erythroblasts. But when they get out into the blood stream their nuclei decay and a cell without the nucleus is only half alive. In particular, they completely lose the ability to reproduce themselves, since cell-division is a process governed completely by the nucleus. All they can do now is just to carry the loads of oxygen from the lungs to the body cells, and the loads of carbon dioxide from the body cells to the lungs, thus supporting the life of the entire cellular colony."

"Like oxen or mules," inserted Mr. Tompkins.

"Yes, very much so," smiled Dr. Streets, "and as load-carriers they are, of course, completely indispensable."

"Are they deprived of their reproductive power," continued Mr. Tompkins, "so that their sex instincts do not interfere with their work?"

"Maybe, maybe," said the doctor reflectively, "although, of course, there are many cases (the frog's blood for example) where erythrocytes retain their nuclei all the time while in circulation. Again, in the case of a man who for some reason or other has lost a lot of blood, immature erythroblasts are poured into the blood stream to support the dwindling cargo traffic. So it really doesn't make much difference. When erythrocytes die they are disintegrated in your liver and spleen, and their remains are removed through the urine."

"But what about the *white blood cells?*" asked Mr. Tompkins. "Do they carry some special load through my body?"

"Oh no," replied Dr. Streets, "white blood cells, or *leucocytes* have nothing to do with the Traffic Department. They are rather the members of the National Guard, and their job is to

protect the cell community from outside invasion. Like all real soldiers they always possess a brave nucleus. We also call them *phagocytes,* or 'cell eaters' (in Greek *phagos* stands for 'eating'), since they would attack and eat up most of the invading foreign cells. If you look around you will notice a few of them floating through the blood stream and maintaining law and order. If they notice a bacterium, they will attack it right away, envelop it with their protoplasm and devour the invader in less than half an hour. If the invading bacteria are not in the blood stream but somewhere in the lymph between the body cells, phagocytes force their way through the walls of the blood vessels and 'get their man' all the same. Their trouble is, however, that, in order to catch the bacterium, they must pin it against some solid wall, like the wall of the blood capillary for example; or else several of them have to attack the bacterium from different sides. If you look this way, you will see how it is done." Looking in the direction of Dr. Streets' finger Mr. Tompkins noticed several phagocytes who had cornered a bunch of bacteria and were getting ready to devour their prey. "If the bacterium floats in the middle of the blood plasma," continued the doctor, "it is very difficult for a single phagocyte to grab it; about as difficult as it is for you to catch with your teeth an apple floating in a bucket. That is because most bacteria possess rather tough skins, the so-called capsules, which make them as slippery as the wet apple. However, the phagocytes are helped in their job by complex chemicals, known as *antibodies,* which appear in the blood during each bacterial invasion, 'softening up' bacterial skins as well as neutralizing the poisonous substances or toxins excreted by the bacteria into the blood stream."

"I take it," said Mr. Tompkins, "that these antibodies are not living creatures, since you refer to them as chemical."

"Quite right," agreed Dr. Streets. "They are chemical—though rather complicated. The amusing thing about them is that they do not originally exist in the organism, and are produced only when the organism is attacked for the first time by some bacteria or other. When such an attack occurs, the organism begins to produce antibodies specially suitable for the defense against that particular invader. They are, so to speak,

tailored for each type of invader, and fit in like a key into a lock. It is likely that any living organism possesses, to start with, raw material for making the antibodies which can be quickly molded into any suitable form. You might imagine, as an example, a locksmith's shop with a large collection of uncut keys. When the locksmith is called on to open a new and complicated lock, he would probably use a skeleton-key which can be adjusted and fitted into the lock by trial and error. This may be a lengthy process, but once it is done the locksmith can easily produce any number of keys answering the same purpose. And, if he is shrewd enough, he will keep a sample of that key in case he meets with an identical lock sometime in the future."

"Isn't that what doctors call *immunity* against the disease?" asked Mr. Tompkins.

"Just so," was the answer, "and to form such an immunity as a preventive measure, we inject into a person a certain amount of dead bacteria, which, not being able to multiply, can cause no harm, but can still induce the organism to work out a suitable antibody to be used in case of actual invasion. This method. . . . Oh, wait a second!" And Dr. Streets broke off, rising to his feet and trying to catch something floating through the plasma past their erythrocyte. "I think I can now diagnose your illness."

He was holding between his fingers a slippery object about the size of an apple.

"Is that a bacterium?" asked Mr. Tompkins.

"Oh no! On our scale a bacterium would be as large as a dog. What you see here is a virus particle, and I would bet my professional pride that this is nothing else but the influenza virus."

"Oh, 'flu," drawled Mr. Tompkins with relief; "so there is nothing to worry about!"

"Well, sometimes one can have a nasty case of 'flu. But I think you will be all right, and if you look here I will show you why."

With these words Dr. Streets pulled at the object he held in his hands, and it easily separated into two parts. In his left hand was a round body with a rather rough-looking surface, and in his right a semicircular shell into which the other part was previously fitted.

"You see now," explained the doctor, "this sphere here is the influenza virus, a single molecule built from many millions of individual atoms. You must have heard, of course, about the viruses, which lie halfway between living and non-living matter, and are sometimes called 'living molecules.' While bacteria can be considered as a kind of plant, secreting poisonous substances into the body of the organism they attack, viruses are the living poisons themselves. We may consider them as regular chemical molecules, since they always have a strictly defined atomic structure, but on the other hand we must also consider them as being alive, since they are able to multiply in unlimited quantities. Many diseases, such as influenza and poliomyelitis in humans, foot-and-mouth disease in cattle, and mosaic sickness in tobacco plants, are due to viruses, not to bacteria. And when you are attacked by a virus disease your organism learns how to produce the antibodies which can cope with that emergency. The empty shell which I hold in my right hand is the antibody for the influenza virus which covers it up and renders it inactive. Look how closely the surface details of the virus particle fit into the corresponding details on the inner surface of the antibody; this is the key-lock relationship I was talking about before. These antibodies float in large quantities through your blood stream, catch the virus particles, clog them into clusters, and later eliminate them from your system. Since this particular virus particle, and a few others which I have noticed floating by, are already taken care of by the antibodies, I would expect that your 'flu will not develop into anything serious. I don't think you need even stay in bed."

"I think I like that key-and-lock analogy," said Mr. Tompkins, reflectively, "but I don't quite see who is the locksmith. Who makes them fit?"

"I don't see it too clearly myself," said Dr. Streets, "and I doubt whether even my good friend, Linus Pauling of California Institute, who is an ardent advocate of the key-and-lock analogy, can tell you much more about it. The fitting is apparently done by the attractive forces between the atoms in the attacked invading particles, and those in the attacking skeleton-key antibody. I admit that it seems at first sight almost unbelievable that simple atomic forces can produce such remarkable

structures, but you may begin to think differently if you remember the fantastic shapes of stalactites and stalagmites which are produced by nothing but water solution of calcium salts leaking through cave ceilings."

Dr. Streets carefully fitted the influenza virus back into its antibody shell, so that it would not cause any more harm, and released it into the blood stream.

"Aren't these antibodies going to attack me, since they must certainly consider me to be a foreign body in my own blood?" asked Mr. Tompkins with some trepidation, "or would it be too silly to develop immunity against myself?"

"They certainly would if you stay here long enough," the doctor assured him. "But since you are, so to speak, a single particle, and don't multiply, it will take a long time to raise the alarm. However, it often happens that antibodies attack particles which are meant to be beneficial to the organism. That is why, in all blood transfusions, one should be very careful to select the proper type of donor."

"Oh, the blood groups," exclaimed Mr. Tompkins. "I never thought that problem was connected with the disease-fighting agencies."

"It certainly is," retorted Dr. Streets. "If, by some mistake, you had injected into your blood stream the blood of a dog or a pig you would become seriously ill, since your antibodies would start a violent and devastating campaign against the alien erythrocytes. You might even die from thrombosis, as the doctors call it, if the debris of the battle clogged the capillaries and prevented the circulation of blood. Now, within the same species the blood is largely interchangeable, but not quite. Human red blood cells may contain, among many other things, two particular proteins known as A and B. The blood plasma may contain, on the other hand, the antibodies acting against these proteins; anti-A and anti-B we can call them. In some persons neither of these two antibodies is present, and they live happily with both A- and B-proteins in their blood cells. We call them A + B blood-type individuals. In other persons either anti-A or anti-B is absent (the other being present), so that erythrocytes may contain A or B proteins respectively. These are A and B blood types. Finally, it is possible that both antibodies are

present in plasma, which leads to the O-blood type, deprived of both A and B proteins. In any individual human being the balance between the proteins and their antibodies is established from the early embryonic stage and there is no trouble. Again, if a blood transfusion takes place between two persons of the same blood type no harm will follow. But if the blood from an A-donor enters the system of a B recipient, the anti-A of the recipient's plasma will attack the erythrocytes of injected blood. This fight may often be fatal to the patient."

"I see now why they use plasma," exclaimed Mr. Tompkins. "If the red blood cells are absent no fight can take place."

"You are nearly right, but not quite," corrected the doctor. "Even if the injected blood has no erythrocytes, it still contains in solution the antibodies which would attack the erythrocytes of the recipient blood, unless, of course, the donor is of A + B type. The point is, however, that mixing in a proper proportion the plasma obtained from persons of different blood types, one can prepare the so-called 'pooled plasma' in which the concentration of both antibodies, though not exactly zero, is sufficiently low not to cause any harm. But I am afraid I am getting too technical, and we'd better spend the rest of our time in surveying the other wonders of the blood stream. I still have to show you some hormones and vitamins."

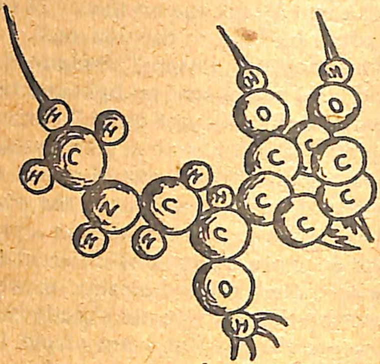
"Are they also living molecules?" inquired Mr. Tompkins.

"Oh, no," said Dr. Streets. "In many cases they are rather simple, and some of them can be synthesized from inorganic chemical compounds. *Hormones,* for example, whose name was derived from the Greek word *hormao* meaning 'to stir up' or 'to excite,' are sometimes built from as few as a couple of dozen individual atoms. They are not the high executives of life, being more like orders or instructions sent out by these executives. They are just sheets of paper marked with ink carried around by couriers, but absolutely necessary for the smooth functioning of the business. If you take my lens and inspect the plasma floating past your palm you may be able to see some of these particles."

Following the doctor's advice and watching carefully the passing parade of the inhabitants of blood plasma, Mr. Tompkins soon noticed a very interesting object. Under the lens it

looked like one of the dragons seen in the streets of Chinatown during the New Year celebration. But it was less than one millimeter long, and (as Mr. Tompkins rapidly counted), was formed of only twenty-two atoms.

"This is a molecule of *epinephrine* or 'scary harmone' which is produced by certain glands near the kidneys every time a



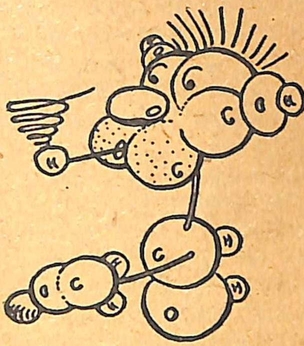
Epinephrine, or "scary" hormone.

person is frightened. Being rapidly carried by the blood stream through the entire body, this hormone speeds up the action of the heart, causes the blood vessels to contract—thus increasing the blood pressure—and causes a release of sugars from the liver, providing the immediate source of extra energy for escaping the danger. The one which you have just seen is probably left over from the moment when you were scared by believing yourself on a sinking submarine. There are also many other hormones in all walks of life such as, for example, *secretin* which induces certain glands (pancreas) located just below your stomach to produce digestive juices at a higher rate, *testosterone* or male hormone which makes a man a man, and *theelin* which makes a woman a woman."

"But what about *vitamins*," asked Mr. Tompkins, "are they in my blood stream too?"

"I am pretty sure of that," replied Dr. Streets, "since I be-

lieve your wife gives you the right sort of meals. Vitamins, as you probably know, are obtained from the proper foods and are absolutely necessary for health. A man needs over a dozen different vitamins, all of them comparatively simple substances which can be in many cases produced synthetically from inorganic material. You must certainly have heard about vitamin C



Vitamin C, found in spinach.

which is present in spinach, green peppers, orange juice, and tomato juice, and so on. Unless you get about sixty milligrams of that vitamin every day, you are liable to get scurvy: your gums begin to bleed and your teeth become loose. On the other hand the lack of vitamin A—found in butter, fat, and fish-oils—causes a scaly condition of the eyes and night-blindness; whereas vitamin D (found in cod-liver oil) serves to prevent rickets, a disease involving malformation of the bones and unsatisfactory development of the teeth. But you can certainly find all the information about vitamins in any book on food and nutrition.

"You'd better look around now since we are entering one of the *villi* of your small intestine. Here is the place where the blood absorbs the digested food you ate this morning, in order to carry it round to all the cells of your body. If you look through the thin transparent layer of cells separating us from the 'inside of your insides,' you will notice a brownish mass of

what was once bacon and eggs. It is now completely broken down by the digestive enzymes. The food you eat consists essentially of three chemical types: proteins, carbohydrates, and fats. The three types of enzymes, known as *trypsin, amylase,* and *lipase* attack respectively these three main food components, turning them into much simpler substances. Heavy protein molecules are broken up into much simpler amino acids, carbohydrates are turned into sugars, and fats are split into glycerine and fatty acids. All of these substances are soluble in water and diffuse through the thin walls into the villi. Once inside, amino acids and sugars get into the blood capillaries and are immediately dispatched into all parts of the body where they are expected by the hungry cells.

"The product of fat digestion is however much slower. Instead of choosing fast transportation through the circulatory system, they recombine again into tiny fat globules and move in a horse-and-van fashion through the lymphatic system. Lymph, as you may know, is a fluid very similar to blood plasma which fills the spaces between the tissue cells. It forms a waterway system as intricate as the channels in Florida's Everglades, where only the native Indians can find their way. And, like the Everglades' network of waterways, it is mostly stagnant water with very little or no current. So fat globules often form local congestions, causing fatty deposits in various parts of the body."

"Did you say," asked Mr. Tompkins, who was hardly listening to Dr. Streets' later remarks (which had got a bit dull anyway), "did you say that there is still some bacon and eggs left on the other side of the villi's walls? Since I've gone without my lunch I certainly shouldn't mind eating my breakfast all over again."

And, before the doctor could hold him back, he dived from their erythrocyte, and was already making his way through the thin layer of villi-cells separating him from the inside of his insides.

"Come back!" shouted Dr. Streets in despair. "You will be eaten up by your own digestive enzymes.

"Too bad," he added, seeing that all his attempts were of no avail, "I should have told him about ulcers—when a man eats his own stomach."

LEONARD ENGEL

ACTH, Cortisone, & Co.

One of the objects of the study of life and of man is discovery of ways of treating disease. Few such discoveries have had a greater or more dramatic impact than the uncovering of the striking effects of ACTH and cortisone in a long list of the diseases that human flesh is heir to. The article below (by the editor of this volume) was originally published in the August, 1950, *Harper's Magazine*. Three remarks are needed to bring it up to date. First, cortisone is probably not a true hormone of man; hydrocortisone is now believed to be the anti-inflammatory hormone of the normal human adrenal cortex gland. Second, the sodium or salt-regulating hormone referred to in the article was finally isolated in 1953 by a team of Swiss and English chemists headed by the brilliant T. Reichstein; it is called aldosterone. Third, the synthetic anti-rheumatic drugs pointed to by cortisone have begun to materialize, in the powerful new prednisone family of anti-rheumatic drugs such as Meticorte.

One day in the spring of 1949, a doctor with a friendly eye and a pug nose exhibited a motion picture which has still been seen by only a few audiences—mostly medical—but has created more stir than anything that ever came out of Hollywood. The doctor was Philip S. Hench of the Mayo Clinic, and the film was a modest two-reeler showing the dramatic effects of cortisone, a hormone of the adrenal cortex gland, on rheumatoid arthritis.

Cortisone and a companion substance, ACTH, have scarcely been out of the papers and magazines since. They have been found to play some kind of role—relieving, provocative, or other—through practically the entire spectrum of disease. By now, the score stands something like this: these two substances

temporarily relieve not only rheumatoid arthritis, but gout, spondylitis, Still's disease, and several other forms of arthritis; rheumatic fever; the fatal skin diseases disseminated lupus erythematosus, scleroderma, and dermatomyositis; uveitis, choroiditis, and retinitis pigmentosa, three eye disorders which usually lead to blindness; myasthenia gravis and other debilitating muscular disorders; pemphigus; ulcerative colitis; allergic arterial disease, asthma, hay fever, and allergies generally; and Hodgkin's disease, lymphatic leukemia, and several additional types of cancer. Adrenal cortical substances may also be valuable in treating secondary shock, burns, fractures, and other severe physical injuries, chronic alcoholism, and, under special conditions, infections like tuberculosis and pneumonia. Adrenal cortical hormones are, of course, directly involved in the primary disorders of the adrenal cortex: Addison's disease, Cushing's syndrome, precocious sexual development, pseudo-hermaphroditism, and virilism. In addition, improper functioning of the adrenal cortex may have a part, direct or indirect, in hypertension, arteriosclerosis, kidney disease, diabetes and, finally, the major mental disorders, schizophrenia and manic-depressive psychosis.

The hormones of the adrenal cortex are clearly potent biological substances. None comparable to them has ever been found. Endocrinology, the study of hormones, began in 1902 with the discovery by the English biologists Bayliss and Starling of the first hormone, secretin, a substance produced by the lining of the intestine and carried in the blood to the pancreas to start the flow of pancreatic digestive juice. In the next decade, a dozen similar "chemical messengers" secreted by special glands and carried by the blood to the organs on which they act were uncovered. The thyroid was quickly shown to produce a powerful hormone, the medullary part of the adrenal, another, and the pituitary, several more. The gonads—the ovaries of the woman and the male testes—were proved to be the source not only of the germ cells that carry on the race, but of powerful internal regulatory secretions as well. Later, the parathyroids, a group of tiny bodies embedded in or next to the thyroid gland, and the "islands of Langerhans" within the pancreas were also shown to produce important hormones. As each

gland was identified, enthusiasts within and without the scientific world hailed it as a key to health and disease, growth and aging, the whole complex mechanism of the body. The gland which may actually turn out to warrant this billing is the adrenal cortex, whose functions are only now beginning to be understood.

The adrenal cortices are the outer part of the adrenal glands. Resting atop each kidney like miniature cocked hats, the adrenal bodies are deeply folded bits of tissue roughly triangular in shape, two inches long, and a tenth to a third of an inch thick. Together the two weigh no more than a quarter of an ounce—about 1/9000th of the total body weight. Each has a thin central section and a thick outer layer. The former is the adrenal medulla, source of the stimulating homone, adrenalin. The outer part, the cortical gland, comprises 90 to 95 per cent of the whole adrenal body.

The cortex and medulla arise from different embryonic tissues and have at most only an indirect connection with each other. In many varieties of fish, they are entirely separate; why they have come together in the long climb of vertebrate life upward from the sea is a mystery. At any rate, the cortex is not only much the larger part of the adrenal body but incomparably the more important. It is the one indispensable gland of internal secretion. Should accident or disease destroy any of the other glands, the result might be serious dislocation of normal bodily functioning and severe illness, but not immediate death. Even failure or loss of the pituitary gland, the "conductor of the endocrine orchestra," can be survived for some time. Death follows in a few weeks at most, however, if all adrenal cortical tissue is destroyed. Most of the endocrine glands, a biochemist friend of mine has remarked, are comparable to limbs; they are dispensable. But the adrenal cortex is like the heart; it cannot be done without. There are no other equally small bits of tissue, except the brain centers for controlling breathing and maintaining blood-vessel tone, whose destruction brings death so quickly.

The adrenal cortex is deeply enmeshed in basic metabolic activities, such as the supply of carbohydrate fuel to the muscles and the balancing of major components in the blood, and

it has specific functions in growth and development. Most important of all, it is a defense *against our defenses*. The ceaselessly changing environment in which we live continually presents challenges—fluctuating temperatures, varying demands for physical activity, injury, the assault of microbes—which we meet with a variety of appropriate defense measures. A wound, for example, calls forth a host of special activities: tissues are made permeable to body fluids bringing building materials to the site of the injury, white blood cells are mobilized to remove dead tissue and halt invading germs, and so on. Necessary as they are, such measures upset the fine balance of the internal economy; unchecked, they would soon lead to fatal shock.

The adrenal cortex acts to restore the balance, creating a new equilibrium that permits the body simultaneously to carry on routine activities and to meet the immediate challenge. This is what is meant when biologists speak of maintaining the integrity of the organism. Health and illness, life itself, depend directly on how long and how well the adrenal cortex discharges this function, and on what sort of response other tissues and organs make to its demands.

II

In order to appreciate the role of the tricorn kidney caps in disease, we need a more precise picture of what these tiny glands do and how they do it. A convenient approach can be made through the symptoms of a disease with which they are intimately connected. Addison's disease, fortunately quite rare, results from infection or atrophy of the adrenal cortical tissue. It was first described a century ago by the celebrated English physician Addison, an observer with rare powers of discernment, whose only error lay in supposing that the adrenal bodies as a whole were responsible; we now know that damage to the medulla is incidental and that destruction of cortical tissue is the source of the disease's devastating consequences. Without hormone extracts and other modern therapeutic aids, Addison's disease is invariably fatal in one to three years if five-sixths of the cortical tissue is involved, and in days or

weeks if all is.

The initial sign of Addison's disease is a bronzing of the skin, which may come so insidiously that at first the patient thinks he has acquired a tan. As the color of the skin deepens, extraordinary muscular weakness and languor develop. Physical activity of any kind demands a palpable effort; a response becomes a study in slow motion. The disease may rest here for some time, depending on the extent of damage to the adrenals. A hypodermic injection, a minor cut, any kind of trivial stress, however, may set off a catastrophic crisis.

But the crisis may finally come without any obvious precipitating cause. Vomiting sets in and continues almost without rest; gastric acid disappears from the stomach, and marked changes take place in other digestive juices; simple food substances, like glucose, which are ordinarily rapidly absorbed seem unable to pass the intestinal barrier. The body temperature drops several degrees below normal. Catastrophe also overtakes the blood and circulatory system; sodium (salt ion) and water leak out of the blood through the kidneys—and consequently the volume of the blood rapidly and visibly declines. Meanwhile, toxic nitrogenous wastes and potassium—usually eliminated—are retained; their concentration in the diminishing volume of blood soon reaches dangerous proportions. The final act in this terrible biological drama comes when the glucose level of the blood falls away to zero, as though from a fatal overdose of insulin.

The Addisonian patient is a picture of total disintegration. In the absence of a sufficient supply of cortical hormones, the finely balanced human organism degenerates into a Babel of unrelated biological processes working at cross purposes. Several of the main areas in which the adrenal cortex is involved can nonetheless be made out at once. To begin with, we can see the role of the adrenal cortex in preventing shock; the slightest stress throws the Addisonian patient into an irreversible shock episode. A number of the individual metabolic processes directly under adrenal cortical control are also revealed. One is the supply and employment of carbohydrate fuel in the muscles. Carbohydrate reaches the muscles—from the liver and, in emergencies, from lymph and other body cells whose proteins

can be broken down into glucose—by an involved series of processes. Cortical hormones intervene in them at several important points and also regulate the rate of combustion of carbohydrate in the muscles. Without the secretions of the adrenal cortex, the muscles' small stores of fuel are speedily exhausted and cannot be replaced. Muscular activity grinds to a halt, and the body temperature, which is closely dependent on muscular activity, falls. In addition, cortical hormones help make the circulatory system leakproof, and they exert a decisive influence on the composition of the blood, conserving water and sodium, and keeping down the concentration of potassium and nitrogenous wastes.

These functions are more than enough to make the presence of the adrenal cortex felt in every corner of the body. But cortical tissue has important functions beyond those readily discerned in Addison's disease, particularly in connection with the nervous system, and growth and reproduction. As we shall see, there is strong evidence of a direct association between the nervous system and the cortical glands. For the moment, I will confine myself to a curious structure called the "fetal cortex."

This is an extra layer of adrenal tissue which appears early in prenatal life, begins to be replaced by adult cortical tissue some time before birth, and finally disappears during infancy. The fetal cortex is fully developed only in man and his fellow primates, and probably plays a critical part in the development of their chief glory, the most elaborate brains in the animal kingdom. At any rate, in many forms of congenital idiocy, the outstanding finding—aside from defects in the brain itself—is an almost complete failure of the adrenal cortex (including the fetal cortex) to develop; the cerebral monster's adrenal glands often weigh as little as seven per cent of normal. As for growth and reproduction, young laboratory animals whose cortical tissue has been removed can be kept alive and in good health with hormone substitutes, but they neither grow nor mature. Overactivity of the adrenal cortex, on the other hand, also halts growth but accelerates and often grossly distorts sexual development.

The adrenal cortex must be one of the busiest and most di-

versified of the body's chemical factories, for its major functions are probably carried on by separate hormones. There is at least one (called the sodium factor) for regulating the sodium, potassium, and water content of the blood. Another, the gluco-neogenetic factor (possibly a group of substances rather than a single hormone) has to do with carbohydrate metabolism. Growth and reproduction functions are discharged through sex hormones. The adrenal cortex puts out—in men and women alike—androgens (male sex hormones), estrone (female sex hormone), and progesterone (corpus luteum or gestation hormone); the adrenal cortex is, in fact, the chief source of sex hormones until adolescence and remains an important one throughout life.

No less than twenty-eight substances showing hormone activity have been isolated from adrenal extracts. Not all are actually cortical hormones; some, possibly a majority, are merely intermediates, half-finished hormones caught by the exploring biochemist in mid-process. The known adrenal substances, in any case, do not wholly duplicate the activities of cortical tissue. Important cortical hormones remain to be identified. All so far isolated belong, like the ovarian and testicular sex hormones, to the remarkable class of chemicals known as steroids. To this group also belong the bile acids; cholesterol, a fatty substance deeply implicated in hardening of the arteries; the heart stimulant, digitalis; and a great many of the chemical agents that can cause cancer—biologically powerful substances every one.

Only a minor quantity of hormones are actually stored in the adrenal cortex. The greater part are manufactured as needed. The agent that turns the glandular factories—at least, most of their "production lines"—on and off is another hormone, from the pituitary gland. The pituitary is a body roughly the size of a kernel of corn hidden in a recess of the skull at the base of the brain. It consists of anterior and posterior lobes, of which the latter, the smaller of the two, is secondary in importance. From the anterior lobe, however, come half a dozen potent secretions which orchestrate the activities of the major endocrine glands and through them profoundly influence the body as a whole.

One of the anterior pituitary substances is ACTH, adrenocorticotropic (adrenal cortex oriented) hormone. ACTH regulates the output of the adrenal cortex (with the possible exception of the sodium factor, whose output presents anomalies), now holding it at a comparatively low "resting level," now shooting it sky-high in response to stress. If the anterior lobe of the pituitary is excised, cortical response to stress is abolished. The cortex continues to secrete enough of its hormones to carry the organism along for a time at a very low level of existence, but there is no outpouring to regulate the body's defenses in time of emergency. The secretion of ACTH is itself governed by the body's varying needs. As the supply of cortical hormones circulating in the blood is used up, the pituitary releases ACTH; as the cortical hormone supply rises, the secretion of ACTH is shut off.

III

Most of our information about the adrenal cortex is recent in origin. Despite the efforts of Addison and several of his contemporaries, the adrenal cortex was largely *terra incognita* until 1930, when Frank A. Hartman and Katherine A. Brownell of Ohio State University, and W. W. Swingle of Princeton and Joseph J. Pfiffner of Parke, Davis, and Company prepared the first cortical extracts to show unequivocal hormone activity. Five years later, the chemists Edward C. Kendall of the Mayo Foundation for Medical Education and Research and T. Reichstein of Switzerland had isolated the first pure adrenal steroids, permitting the start of systematic experimentation to distingiush among the several functions of the adrenal cortex. But only one cortical substance, a somewhat dubious one at that, was available in any quantity for several years.

Progress remained comparatively slow until a rumor reached Washington, shortly before Pearl Harbor, that the Germans were buying up the adrenal gland output of the Argentine slaughterhouses and obtaining cortical extracts which enabled Luftwaffe pilots to fly and fight at 40,000 feet. The rumor was false, but set in motion the Army and Navy medical depart-

ments. Nearly all of the twenty-two American and Canadian laboratories that had carried on investigations of the adrenal cortex were enlisted in an emergency research program. This program not only led to processes for producing respectable quantities of cortisone and other adrenal corticoids, but directly paved the way for their present spectacular offensive against disease.

The first experiments to establish clearly the link between the adrenal cortex and disease were performed by Hans Selye, a Viennese-born biochemist and physician, director of the Institute of Experimental Medicine and Surgery at the University of Montreal. About a dozen years ago, Selye, then on the staff of the McGill University Medical School, set out to investigate the response of rats to a variety of drugs, poisons, and gland extracts. He injected large enough doses of such diverse substances as strychnine, atropine, formalin, and crude pituitary extract to kill in a day or two, and autopsied every animal with care. He expected to find changes characteristic of each drug. In three of the animals' organs, however, he found precisely the same changes regardless of what he had injected: the adrenal glands were swollen to twice or three times their usual size and were dark brown in color instead of the normal yellow; the thymus, a mass of lymphatic tissue in the space between the lungs over the heart, had wasted away; and the lining of the stomach was spotted with bleeding ulcers.

It appeared to Selye that he was witnessing a general reaction to damage and that any stress threatening to life would elicit an identical response. He quickly confirmed this by subjecting animals to a variety of other stresses: fasting, excessive exercise in an ingenious rat work machine, swimming to exhaustion, exposure to freezing and to very high temperatures, severe physical injuries, and terror. Whatever additonal changes might be associated with particular stresses, he always found swollen adrenals, a withered thymus, and bleeding stomach ulcers.

Selye termed the unmistakable common response to severe stress the "alarm reaction." Further research showed that the alarm reaction has a "shock phase" and a "countershock phase," each accompanied by characteristic changes in the tis-

sues and body fluids. In the shock phase, during the first few hours of exposure to stress, the concentrations of sugar and sodium in the blood drop, the number of circulating lymphocytes (a type of white blood cell derived from lymphatic tissue) rises, and the blood pressure falls. A few hours later, in the countershock phase, the changes are reversed: blood sugar and sodium rise above and the circulating lymphocytes drop below normal, and the blood pressure rises. The changes in the adrenal glands, thymus, and stomach lining coincide with the second phase rather than the first.

Both the anatomical and physiological changes of the countershock phase, in fact, are due to the great enlargement and increased activity of the adrenal cortex. If the adrenal glands are surgically removed, the animals lose all resistance to stress whatever, never reach the countershock stage, but swiftly succumb to shock. In intact animals, on the other hand, the adrenal cortex swiftly lays down extra secretory cells in an effort—vain, of course, in the case of animals exposed to the heaviest stress—to offset the shock phase.

Selye then turned his attention to a pertinent second question. What would happen if his laboratory rats were subjected to less intensive but more prolonged stress? Animals were exposed over a period of weeks to daily doses of stress insufficient to kill, and sacrificed at intervals to determine what internal changes might be taking place.

The Canadian biochemist-physician found the same alarm reaction—first shock, then countershock. In this series of experiments, however, the animals survived the countershock stage and began to revert to normal; so to speak, they learned to live with the stress. The extra cortical secretory cells were absorbed and the adrenals shrank to pre-morbid size, the thymus regained its original proportions, and the blood picture returned to normal. It was difficult to tell the test animals, in these particulars, from the controls. But the return to the prestress condition was more seeming than real; critical differences remained. First, the "stage of resistance," as Selye called the apparent recovery, lasted only a month or two. If the stress was continued, the internal equilibrium achieved in the resistance stage ultimately collapsed and a stage of exhaustion

set in. The latter closely resembled the initial alarm reaction and swiftly ended in death. Second, resistance to other stresses decreased as resistance to the original stress built up; exposure to a new stress during the stage of resistance led to the immediate collapse and death of the animal. Third, beneath the surface of seeming normality, other organs often exhibited marked pathological changes. These frequently bore a startling resemblance to grave human ailments, such as hardening of the arteries.

It thus seemed to Selye that rats are endowed with a fixed "adaptation capital" for overcoming stress. Their adaptation energy can be spent only once, and life ends when the stock is used up. Moreover, the process of adjustment to stress may itself produce "diseases of adaptation" that shorten life. In the complex events of the adaptation process, the adrenal cortex occupies a central place; in a sense, the cortical glands are the bank in which the adaptation capital is stored.

IV

In 1878, the pioneer physiologist Claude Bernard of France called attention to the remarkable constancy of the internal environment. Many years later, Walter B. Cannon elaborated Bernard's observation into the concept of homeostasis, a cornerstone of contemporary biology. Living organisms, from microbes to man, are self-adjusting systems, something like a thermostatically-controlled household furnace. In quite the same way as the thermostat manipulates the fuel supply to maintain a prearranged temperature in the house, so the diverse internal activities of the living organism are regulated to keep the internal economy as a whole functioning at a nearly constant level. Shifts imposed from the outside promptly set in motion correcting counter-shifts. Without this capacity for homeostatic adjustment, no living organism could survive. Selye's studies have identified the adrenal cortex as the immediate effector of many of the most important homeostatic changes and have shown graphically the relationships between stress, homeostasis, and disease.

Most of Selye's experiments were performed with rats. It

will take many years to confirm his conceptual scheme in its entirety, particularly the notions of the fixed adaptation capital and the diseases of adaptation, and to extend it, in meaningful detail, to other species. The generality of the alarm reaction and the resistance and exhaustion processes, though, has been amply demonstrated throughout the higher vertebrates. The alarm reaction has also been established for man by measurement of adrenal cortical output during illness and in response to other stresses.

As frequently happens in research, a link between the adrenal cortex and one disease, rheumatoid arthritis, was inferred before anyone appreciated the deep involvement of the adrenal cortex in disease generally. More than a generation ago, physicians noticed that pregnancy and attacks of jaundice brought temporary relief from rheumatoid arthritis, a malignant variety of arthritis distinct from and much more severe than the common wear-and-tear osteoarthritis of old age. The clue was taken up about 1930 by Philip Hench. From study of the stream of patients passing through the Mayo Clinic, Hench became convinced that pregnant women secreted an anti-rheumatic factor, and that this factor was a cortical hormone. (His belief was afterward confirmed by the studies of Dr. Eleanor Venning of McGill, which showed that the output of cortical hormones soars to many times the usual value during pregnancy.)

Hench tested a mixed cortical extract as a possible arthritis remedy shortly before the war without result, and later, also without result, a pure preparation of one of the first adrenal steroids to be isolated, a substance known as Kendall's Compound A. The next pure adrenal steroid to become available was Kendall's Compound E, or cortisone, made by Merck and Company using a technique suggested by Kendall. The first clinical samples were delivered to Hench in September 1948. What happened then has already become a part of science-magic folklore. Hench and two associates, Howard F. Polley and Charles H. Slocumb, made the trial on fourteen rheumatoid arthritis patients, some totally unable to move, all severely incapacitated. Three days or less of treatment with cortisone brought complete freedom from pain and as much freedom of

movement as damaged joints would allow. The relief lasted as long as the injections could be continued.

No additional cortisone was available for several months. In the meantime, however, University of California and Yale biochemists had succeeded in extracting ACTH, the hormone governing the activity of the adrenal cortex, from the pituitary glands of livestock. It seemed to Hench that ACTH might take cortisone's place, stimulating the arthritis patient's adrenals into manufacturing, along with other cortical hormones, the needed extra supply of cortisone. Hench obtained a few grams of ACTH from Armour and Company, which had undertaken to extract ACTH from the pituitary glands of hogs on a commercial scale, and made the test. The pituitary hormone duplicated the anti-rheumatic activity of cortisone in almost every detail.

Rheumatoid arthritis is a disease of the connective tissue. There are also many other diseases of the tissues forming the supporting matrix for the organs and principal structures of the body: rheumatic fever, the leading cause of death among children; gout, which afflicts ascetics as well as the self-indulgent; such fatal skin inflammations as disseminated lupus erythematosus; uveitis, an eye disorder which usually leads to blindness; allergy; and cancers originating in lymphatic tissue. As soon as the remarkable performance of ACTH and cortisone in rheumatoid arthritis became known, there was a rush to try them in these other disorders. In fact, doctors now began to venture the two hormones in apparently every ailment that came to mind, from pneumonia to ulcers of the colon. ACTH and cortisone relieved them, too—so long as the patient continued to receive either drug.

The extraordinary ability of ACTH and cortisone to turn diseases off and on extends, with exceptions such as polio and the main types of cancer, through nearly the whole complex of disease. More than one doctor has been led to make a comparison with the Biblical pool of Bethesda, where whoever first stepped in after the angel troubled the water might be cured of his affliction, whatever it was. *But neither cortisone nor ACTH, though they will bring man more complete control over illness than he has ever had, cures disease.* What they

appear to do is "melt" symptoms by greatly intensifying and prolonging the countershock stage of the alarm reaction; the two substances reinforce the body's own supply of cortical hormones in restoring apparent normality and blocking the visible "host" reaction. ACTH and cortisone, to paraphrase J. S. L. Browne, a McGill endocrinologist and a former associate of Selye, are like an unseasonable hot wind melting an iceberg. The iceberg freezes again—and the symptoms return—as soon as more usual conditions prevail. The underlying disease is little affected.

Last fall, physicians at the Northwestern University Medical School had an instructive experience with ACTH in tuberculosis. A very sick tuberculosis patient was started on the pituitary hormone. Within seventy-two hours, his fever was down and his appetite up, and he began to put on weight. Day by day he could be seen gaining strength. Finally, all signs were gone and he was apparently completely well. His sputum still showed tubercle bacilli, however, and when after three weeks treatment had to be halted, the disease broke out again at once.

It is a nice question, which is still to be investigated, what the end would be if an infection were masked for an indefinite period by ACTH or cortisone. In any event, neither ACTH nor cortisone can be given indefinitely in the quantities generally required to make a patient suffering from one of the serious chronic diseases feel well. As befits substances of their station in the internal hierarchy, the two hormones have many effects beside those desired. These are usually called "side effects," a term implying an incidental relationship to the beneficial activity of cortisone and ACTH. The dangerous, undesired effects, however, embrace many of the main activities of the hormones and will not be easily avoided.

The research groups investigating the use of cortisone and ACTH are virtually agreed that no lasting remissions of most chronic ailments, including rheumatoid arthritis, have been obtained, except in a handful of cases, without simultaneously putting the patient into a "hyperadrenal state." Were treatment continued indefinitely, the hyperadrenal state might end in a devastating fatal disease, Cushing's syndrome. The latter is the counterpart of Addison's disease and results from a tumor-

ous overgrowth of the adrenal glands, making the glands chronically over-active and flooding the system with an over-supply of cortical hormones.

This brings about as many and as dangerous changes as adrenal insufficiency does in Addison's disease. The face fills out into a moon shape, painful deposits of fat accumulate in the trunk and buttocks, women may grow beards and show other signs of masculinization, the bones are demineralized and become soft, limbs turn blue from a defect in oxygen supply, the blood sugar reaches diabetic levels, the blood pressure soars, and the repair of wounds is inhibited. Psychotic personality changes of a manic or schizoid type may also set in. Death, usually from the blood pressure changes, comes in five to seven years. All of the symptoms of Cushing's syndrome have made an appearance, though not together, in patients receiving cortisone or ACTH, and disappeared only when treatment was discontinued.

Despite the formidable difficulties inherent in their use, the two new hormones are of great immediate value. Apart from their role as probes for dissecting the disease process, ACTH has brought temporary remission (though no cures) of some types of leukemia. In addition, a number of recurrent disorders, like gout, can be treated safely with these substances; they should also prove extremely helpful in pulling acutely ill patients through crises. ACTH has also given the surgeon a means of gauging a patient's chances of surviving an operation: if the patient's adrenal cortices respond well to a pre-operative shot of ACTH, the chances are good that he will survive the stress of the operation; otherwise, preliminary injections of adrenal extract will be needed to carry the patient through. Finally, ACTH and cortisone have invested adrenal steroid chemistry with an urgency bound to lead to the early discovery of other steroids with more specific therapeutic properties.

V

We have seen how the adrenal cortex serves as a homeostatic balance wheel in such ailments as arthritis, and how disease may be modified by additional cortical hormones in the form

of cortisone or ACTH, and also what are the disastrous consequences of gross abnormalities of the adrenal cortex, as in Addison's disease. It is perhaps too early to generalize, but subtle disturbances of the adrenal cortex may play a provocative part in several widespread disorders. There is reason to suspect a link between cortical hyperreactivity and neurosis, and between some form of cortical disturbance and high blood pressure. A derangement of the adrenal cortex is clearly connected, in any case, with the tragedy of schizophrenia.

Schizophrenia is at once one of the terrifying social problems of our time and a uniquely baffling scientific enigma. It affects one per cent of the population and annually removes 150,000 men and women, mostly in the prime of their lives, from productive activity to the sterile gray world of the mental institution, for a stay more likely to be measured in years than in months. Schizophrenia is the chief of the group of puzzling disorders known as functional psychoses. The schizophrenic cannot feel straight, think straight, or act straight. His behavior is an unpredictable mélange of the normal and the bizarre. Yet no lesion of brain or nervous system can be found; structurally, they seem intact. The disorder is rooted in the way they function.

There have been many hints of something biologically amiss with the schizophrenic. A notable study of the biology of schizophrenia was conducted over a twenty-year period at the Worcester (Massachusetts) State Hospital. Almost invariably something was wrong: oxygen consumption was too low, vitamin deficiencies were apparent that could not be ascribed to poor diet, the secretions of one or more endocrine glands tended toward the subnormal. But nothing conclusive turned up until the wartime program of adrenal cortex research.

In one of the projects inspired by the Luftwaffe rumor, a group of investigators at the Worcester Foundation for Experimental Biology, directed by Gregory Pincus and Hudson Hoagland, charted the reactions of the adrenal cortex to the pressures of daily life. With a large number of men from the Air Corps as subjects, measurements of cortical activity were made at regular intervals through the day and during tests simulating the stresses of the workaday world. Physical work, changing

temperatures, frustration, the annoyance of arising in the morning were found to bring sharp peaks in cortical output.

Sometime afterward, the tests were applied to schizophrenic patients at the Worcester State Hospital. A striking contrast with normal individuals emerged immediately. As if to confirm the psychologist's description of schizophrenia as a "withdrawn" state, the patients showed *almost no rise in cortical activity* during the tests, and hardly more on awakening at the start of the day. The total quantity of cortical hormones produced over the twenty-four hours was close to normal, but they were generated at a more nearly uniform rate. There were no sharp peaks and valleys reflecting the changing stimuli of the outside world. A later experiment showed that the defect is in the adrenal cortex itself, and not in its governor, the pituitary; the schizophrenic has unresponsive adrenal cortices.

During the past two generations, the key to schizophrenia has been sought alternately in evironmental (or psychological) forces and in biological factors deep within the individual—in the strains of an increasingly complex society, on the one hand, and an ill-defined hereditary "predisposition" to schizophrenia on the other. The Worcester Foundation discovery puts both in a new light.

As yet, little has been learned beyond the bare fact that schizophrenia is associated with an unresponsive adrenal cortex and that treatment with adrenal steroids or ACTH is as much use as flogging a dead horse—it will not help. Through what channels the adrenal glands influence neural activity and the psyche, or where the adrenal defect originates, remain to be determined.

Since the adrenal cortex is intimately concerned in adaptation, however, the Pincus-Hoagland finding suggests that schizophrenia is a consequence of inability to adapt to the complexities of life. In the simile of the neurophysiologist R. G. Hoskins, the schizophrenic is in the position of a man driving a car through congested city streets with throttle fixed. Unable to speed up, slow down, or stop, the driver cannot long avoid a disastrous collision. Similarly, the peculiar breakdown involved in schizophrenia may be the result of too great environmental demands upon an adrenal cortex perhaps insufficiently

flexible to begin with.

One of the distinguishing characteristics of living organisms is the ability to respond to the stimuli of the external world. In higher animals, the adrenal cortices lie at or near the very center of the processes of response, keeping them within bounds and permitting the organism to meet a wide variety of challenges and yet carry on. It is for this reason that the substances secreted by the tiny bits of tissue above the kidneys exert so powerful an influence on so many diseases, and that investigation of the adrenal cortex promises to bring our understanding and command of biological forces to a new level.

Something Extraordinary

There can hardly be anyone in the United States who has not heard of antibiotics and the revolution they have worked in the treatment of infectious diseases. Here is a lively account of how they are found. It is by Berton Roueché, the accomplished journalist who conducts the "Annals of Medicine" department in *The New Yorker*. It is slightly abridged from the form in which it appeared in 1951 in *The New Yorker* and later in *Eleven Blue Men*, a collection of "Annals of Medicine" tales, and is reprinted here by permission of Mr. Roueché and Little, Brown and Company, publishers of *Eleven Blue Men*. At the time the article was written, five antibiotics were in wide use. The number is now more than a dozen; they are effective against diseases caused by large viruses (such as the virus responsible for smallpox) and rickettsiae (the organisms responsible for typhus and related diseases) as well as bacteria. The title of the article refers to a statement about penicillin made by Sir Alexander Fleming in the paper reporting the original discovery of penicillin. Unfortunately, in preparing Mr. Roueché's article for this volume, the quotation from Dr. Fleming had to be omitted.

I spent a couple of hours one afternoon in the biochemical research laboratories of Chas. Pfizer & Co., Inc., one of the oldest and most considerable manufacturing pharmaceutical houses in the United States. There are Pfizer factories in Groton, Connecticut, and in Terre Haute, Indiana, but the company's principal establishment, an aseptic mesa of thirty-odd buildings that includes its entire research plant, is in Brooklyn, in the Williamsburg section. The business was founded there,

in a pink brick building that is still thriftily in use, by two immigrant Württembergers—Charles Pfizer, a chemist, and Charles F. Erhart, a confectioner—in 1849. Their first product was a wormwood derivative called santonin, an essential ingredient at that time of medicines designed to eradicate intestinal worms.

From that fragile beginning the firm gradually expanded its facilities to embrace the manufacture of a robust line of basic drugs and chemical compounds (bismuths, mercurials, iodines, tartars, and the like) and the production, by a fermentation process in which it pioneered, of citric acid. Until about ten years ago, such drugs and chemicals, together with a select alphabet of vitamins, constituted the bulk of the company's output. Although their production is still both large and lucrative, they now account for just half of the firm's total earnings. The other half is derived from the manufacture of antibiotics. An antibiotic is a chemical substance generated by a microörganism, probably in the course of the metabolic process, that has the capacity to inhibit or destroy certain other microörganisms. Organisms that elaborate protective venoms of this sort abound in the turbulent microcosms of the soil. Every ounce of earth contains millions of them. Few, however, generate bactericidal material that is useful in controlling any of the numerous infectious diseases that hound the human race. Most microbial products are toxic, many are intractably volatile, and some are merely innocuous. Of around a hundred and forty more or less adequate antibiotic substances now known to science, only five are widely serviceable. They are penicillin, streptomycin, chloromycetin, aureomycin, and terramycin. Pfizer is one of the largest of all producers of penicillin and streptomycin, and it is the discoverer and sole producer of terramycin. It is, in fact the largest producer of antibiotics in the world. . . .

The president of Chas. Pfizer & Co. is a chemical engineer named John E. McKeen. Mr. McKeen, a native of Brooklyn and a graduate of the Brooklyn Polytechnic Institute, is forty-seven years old but looks about twenty, and he is short and sleek and restless. When I was shown into his office on the afternoon of my visit, he was prowling back and forth before a long row of windows, his eyes fixed on the ceiling, an unlighted cigar

in his mouth, and a roll of blueprints under one arm. At the sound of my entrance, he halted and swung around. "Ah," he remarked, and tossing the blueprints onto a table, moved rapidly across the room to greet me. It was a large and pleasant office, paneled in pine, hung with portraits and aerial views of Pfizer plants, and faintly scented with disinfectant. One of the portraits was a photograph of Alexander Fleming, inscribed "To John McKeen, with Kindest Regards." Mr. McKeen gave my hand a businesslike pump. "You're early," he said. "Good. There's plenty to see. The biochemical laboratory is a fascinating place. I'd hoped to be able to show you around myself, but I can't. Unfortunately, I'm tied up. Don't worry, though. It's all arranged. One of the other officers is going to take over. He'll be along in a minute. . . ."

There was a sound of voices in the outer office. Mr. McKeen cocked an attentive ear. Then the door opened and a stout, pink-cheeked man of about fifty rolled majestically in. He had on a brown suit and a brown necktie, and he was smoking a slim brown cigar. "Gentlemen!" he said cheerfully.

"Hello, Jasper," said Mr. McKeen. He turned to me. "This is the gentleman I was telling you about. Shake hands with Jasper Kane. Jasper is our director of biochemical research. Needless to say, he was a prominent member of the team that gave terramycin to the world."

Mr. Kane extended a rosy hand. "So was John," he said.

"After a fashion," Mr. McKeen admitted. "Off and on. Terramycin was quite a project. It cost us four long years and almost that many million dollars. Not that I begrudge a nickel of it. Or an hour. We were very lucky. We might have ended up exactly nowhere. That's research."

"You just cross your fingers and keep going," said Mr. Kane through a thunderhead of smoke. "Sometimes it pays off."

"In more ways than one," Mr. McKeen said. "One thing leads to another. I'll give you an example. Research has made this company one of the principal producers of citric acid. Our chemists have been largely responsible for all the major developments in that field. Well, that same research is what put Pfizer out in front of antibiotics. Commerical citric acid is a fermentation product. So are antibiotics. That let us in on the ground

floor. When antibiotics appeared on the horizon, we didn't have to scramble around and start from scratch the way most of the other houses did. We already had the basic know-how."

Mr. McKeen sat down on the arm of a green leather chair. "We got interested in antibiotics in 1941," he said with satisfaction. "In penicillin, I should say. That's all there was then. In a way, it was an accident. One of our fermentation chemists happened to come across an article on the subject in one of the British journals—the *Chemical Trade Journal & Chemical Engineer,* I think it was. Penicillin was still in the experimental stage productionwise. The method that Florey and Heatley and Chain and the rest of the Oxford school had worked out was not very promising from a practical standpoint. It was simply a laboratory technique. They hadn't had time to carry it any further. To give you an idea, their rate of recovery was approximately one part penicillin per one million parts of fermentation liquor. That isn't very stupendous. In fact, it's scarcely more than the concentration of gold in ordinary sea water. But they had shown that penicillin could be produced, and that was enough for us. With our knowledge of fermentation, it looked like our big opportunity. We set up an experimental production unit—what we call a pilot plant—over in the lab, and went to work. Then Washington stepped in. I needn't remind you that penicillin was a war product. There's no telling how long it might have taken to crack the mass-production problem if it hadn't been for the war. Five or ten years, at least. But the war provided the necessary impetus. We had to have penicillin and we had to have plenty of it and we had to have it fast. Washington put the best scientific brains in this country and England to work on it. They brought Florey over, and Heatley, and eventually even Fleming. At the same time, they rounded up the pharmaceutical industry. The first penicillin confierence was held on October 8, 1941, in Washington. Three of us—Merck, Squibb, and Pfizer—came away from that meeting pledged to devote all our resources to the problem. In time, of course, the entire industry was enlisted, but we were in from the very beginning. Not only that. I'm proud to say that Pfizer was delivering penicillin to the government as early as the spring of 1942. However, it wasn't until 1944 that any

of us really began to get results. That's when the basic production problem was finally licked. I say problem—actually, it was a dozen problems, but I'm not going to strangle you with technical detail. I'll leave that to Jasper." He smiled. "What it boiled down to was this—the development of a submerged fermentation process. Up to then, we had all been growing our mold on the surface of the liquor. That was Florey's method, and it largely explains why his recovery rate was so low. Surface fermentation utilizes only a fraction of the culture medium. Nothing could be more impractical. But there didn't seem to be any other way to grow the stuff. Mold requires oxygen. American ingenuity found the answer to the riddle. Submerged fermentation is possible because Pfizer engineers evolved a technique for aerating a liquid mass."

Mr. McKeen was silent for a moment. He plucked a bit of lint from his sleeve. Then he cleared his throat. "We've got a great deal to be proud of here at Pfizer," he said. "We're not resting on our laurels, though. That old American competitive urge won't let us. As long as there's a chance of finding one more antibiotic, you'll find Pfizer in there pitching. There's a lot of money in antibiotics. I won't pretend there isn't. But it's more than that. Streptomycin and penicillin and chloromycetin and aureomycin and our own terramycin are more than just commodities. They're more than drugs. They're life-saving miracles. When you make a living by helping somebody else in the world, you've got a pretty good life." He stood up, stuck his cigar in his mouth, and held out his hand. "Or so it seems to me," he said.

The biochemical research plant turned out to be an inscrutable, block-square structure of eight stories directly across the street from the building in which Mr. McKeen and most of the other executives of the company have their offices. Mr. Kane set a leisurely pace toward it. A few steps from the entrance, he drifted to a halt and took a final pull at his cigar. Then, with a grimace of regret, he pitched it away. "We don't smoke in here," he told me. "The only exception to the rule are the administrative offices, the washrooms, and the cafeteria." He swung the door open and led the way across a bleak rotunda to a waiting elevator. The operator was a muscular man dressed

in white, like a hospital orderly. We lurched aloft. "I guess I ought to explain about smoking," Mr. Kane said. "The reason is rather important. It has nothing to do with fire. Practically nothing, anyway. As a matter of fact, the rule applies equally to eating candy. It's a personnel-safety precaution. A considerable part of the work here involves handling pathogenic organisms, and we don't want our people to have any occasion to be constantly raising their hands to their mouths. Of course, we have other safeguards, too—gloves and masks and so on." He smiled a reassuring smile. "Don't be uneasy. I'm not going to take you any place where there's the slightest danger. I can't. It's against the law."

The elevator stopped and we got out. We headed down a long white clinical-looking corridor lined with closed doors. The only sound was the reverberating clomp of our heels. Mr. Kane opened the last door on the left. "Here we are," he said. "Here's where everything starts. This is the mycology laboratory." I followed him into a labyrinth of marble-topped counters, ablaze with sun and laboratory glass—Petri dishes, test tubes, and stubby Erlenmeyer flasks. Moving purposefully about among the counters were three young women in white. One of them gave us a fleeting glance. "A mycologist sounds formidable," Mr. Kane went on, "but he isn't. I happen to be one myself. Mycology is simply the branch of botany concerned with fungi. In other words, this is where we screen samples of soil for microörganisms that look as if they might be capable of producing a useful antibiotic substance. I don't know whether you've ever read any of Selman Waksman's papers. Waksman is not only the discoverer of streptomycin. He's also responsible for a vast amount of basic work. Among other things, he pioneered in evolving the systematic soil-screening technique that we all use now. Well, his account of how he found streptomycin gives a very graphic picture of what we're up against. No one has put it more succinctly. He begins by saying he examined a total of ten thousand samples of soil. From them he obtained around one thousand individual organisms that appeared to possess some antibacterial properties. About one hundred of that thousand, it developed, could actually inhibit bacterial growth. Of the hundred, he was able to isolate just ten.

The rest were too unstable. And of the ten, for various complicated reasons, only one proved to be worth bothering about. That was streptomycin. At that, he was lucky. The odds are steeper now. It's no longer enough just to find a new antibiotic. It has to be superior in some way—in strength, range, or lack of toxicity—to anything else on the market. We went through well over a hundred thousand samples before we hit terramycin. But terramycin wasn't the first antibiotic we hit. The first was streptomycin. So was the second. I guess we've rediscovered streptomycin at least a hundred times. Everybody has. It's quite common." He shrugged. "Only, Waksman got there first."

"Where do you get your samples of soil?" I asked.

"From all over," Mr. Kane said. "India, France, South America—everywhere. We have volunteers combing the earth for us. Airline pilots are among our best sources. And explorers. Whenever we hear of an expedition being organized, we get in touch with the leader. Most people are very obliging. Actually, it's no trouble. All they have to do is— Well, you might as well see for yourself." He stepped to a cabinet and pulled open a drawer, disclosing a litter of lumpy packets, each a trifle smaller than a postcard, and made of transparent cellophane. I plucked one out and looked at it. Clotted in a corner was perhaps a tablespoonful of what could have been powdered mustard. The name and address of the company was stamped on the face of the packet. On the back was a descriptive label. It read: "P. C. Barbour. 20 March 1951. Mozambique, P. E. Africa. 17 Km. E. of Cheline."

I dropped the fragment of Portuguese East Africa back in the drawer. Mr. Kane chuckled. "It doesn't look like much, does it?" he said. "Just a dab of dirt. But appearances are deceiving. Actually, it's a universe. Every envelope in that drawer is crammed with living organisms—molds and yeasts and bacteria of all kinds. I guess *potentially* living organisms would be more accurate. Right now, they're in a dormant or resting state. They're spores. But given the proper environment, they will very rapidly resume their deveopment, and mature and multiply. Microbiological analysis of soil begins with the providing of that environment. You can't learn much from a spore. They all look more or less alike, even under a microscope. A well-

developed colony of microörganisms is something else. Most of them are not only visible to the unaided eye, as you'll see in a moment, but quite easy to identify. Soil analysis is a fairly complicated job. At any rate, it takes time. The first step is to separate into a number of relatively small groups the thousands of spores that are contained in every sample of soil. We do that by mixing half a gram of soil in fifty cc. of water. If you've noticed that girl up there by the window—that's what she's doing with all those flasks. She's making muddy water. That reduces the concentration of spores appreciably. When the soil in a flask has been thoroughly shaken up, we draw off a drop of the suspension—about five-tenths of a cc.—and smear it on a Petri dish containing a nutritive jelly of a sort known to favor the growth of most molds. Then we cover the dish to prevent contamination from the spores in the air, and put it away in the warm room to incubate. At the end of four days, we bring it out and take a look."

Mr. Kane paused, pushed the cabinet drawer to, and peered around the room. Then he touched my arm. "Down this way," he said, and struck off into the maze of counters. I trailed carefully after him along a narrow aisle flanked by hip-high hedges of glass. We emerged before a counter spread with a hundred or so covered dishes. "One of these ought to be enough to give you an idea," he said. "I'd hate to risk polluting something valuable." He reached out, hesitated, and then removed the cover of one of the dishes in the second row. I started. Thrusting up here and there from a sand-gray plain of jelly were a dozen fragile, cottony tufts of brilliant color. Some were as pink as apple blossoms, several were creamy white, others were green or orange or dandelion yellow. One was a dusty blue. It was an astonishingly beautiful sight. It looked like a tiny garden. Mr. Kane grinned. "Pretty, eh?" he said. "Unfortunately, that's about all you can say for this lot. They're all old friends. Most of those white colonies are yeast. The pinks are a variety of mold called Actinomyces. Some members of that family have produced our most valuable antibiotics. Most of them, as a matter of fact. That green one near the far edge is one the whole world knows. It's Fleming's *Penicillium notatum*. Of course, it's merely a curiosity now. Modern penicillin comes from a dif-

ferent strain, a far better producer. It's called *Penicillium chrysogenum.* Kenneth Raper, a Department of Agriculture man, discovered it in 1943, on a rotten cantaloupe he picked up in a market out in Peoria."

"What is that blue one?" I asked.

"Oh, that's a bug," Mr. Kane replied. "Probably one of the Salmonella. You know, the food-poisoning bacteria. They're pretty common. Which is one of the reasons why we don't smoke around here. To tell the truth, though, we don't come across a great many pathogens in the course of screening. Soil isn't the reservoir of disease that most people think. The vast majority of microörganisms are either beneficial or harmless. That's one thing. Another is that most of those that aren't seldom survive for long. About the only serious exceptions are the bacteria responsible for tetanus, anthrax, gas gangrene, and typhoid."

Mr. Kane slipped the cover back on the dish. "Well, that was about an average plate," he said. "Maybe a little under average. We can usually find something of interest. There are hundreds of different molds. Nobody knows how many. We're constantly turning up new ones. Or what look like new ones. Some varieties are impossible to identify until you've seen them in action. Anything that looks at all promising, we isolate for thorough study. None of the girls seem to be working on that phase right now, but no matter. It's easy enough to describe. We simply pick off the colony we want with a sterile needle, drop it into a test tube of jelly, and return it to the warm room for a second period of growth. After about a week, we make another transfer. You can't extract an antibiotic substance from a solid medium. But, as Florey demonstrated, you can from a liquid. So we remove the culture from the tube to a flask of nutrient broth. Then it goes back to the incubator for two or three days or more, depending on its growth rate. Some molds mature faster than others. Then the bacteriological assay laboratory takes over. That's where the cultures are tested for antibiotic activity. I want you to see how we do that. Then we'll have a look at the pilot plant." He raised an immaculate cuff and glanced at his watch. As we moved back up the aisle, he added, "I don't mean to imply that the pilot plant is the last

step. It isn't. A good many antibiotics get that far and still eventually come to nothing. Some turn out to be old friends in disguise. Some turn out to be too toxic. Some turn out to be just plain incapable of functioning in living tissue. They're marvels *in vitro* but worthless *in vivo*. But the pilot plant is as far as I can take you. Everything beyond that stage is restricted, for reasons of sterility or safety."

Two long corridors and a flight of stairs brought us to the office of the bacteriology laboratory. It was a small, tidy room, walled with filing cabinets and furnished with two desks. Behind one of the desks, a young woman was working at a typewriter. She looked up as we entered. "Oh!" she said. "Good afternoon, Mr. Kane. I'm afraid Dr. English isn't . . . Is there anything I can do?"

Mr. Kane resettled her with a genial shake of his head. "We're just wandering around," he said. Skirting the deserted desk, he led me through an inner door, down a short passage, and into a bright, stark, windowless chamber. On the wall, just to the right of the door, hung a framed certificate, signed and sealed by the New York City Department of Health. It read, in part: "Registration of Premises to Handle or Cultivate Live Pathogenic Microöganisms or Viruses." A massive worktable, on which were deployed a number of lidded Petri dishes, stood in the middle of the room. Above it was suspended an angular chandelier of ultraviolet germicidal lamps.

Mr. Kane removed the cover from the nearest dish. In the center, surrounded by a film of jelly, lay a paper disk about the size of a dime. Radiating out from the disk to the rim of the plate, like the spokes of a wheel, were six shallow indentations a trifle darker in color than the jelly. They looked as if they might have been scratched there with the charred end of a match. Mr. Kane gave a grunt of mild disgust. He pushed the dish aside and uncovered another. "Well, that's more like it," he said. "Quite a difference, isn't there?" I nodded. There was. In the second dish, the shadowy spokes were less clearly defined. Only three of the six extended all the way from the disk to the rim. Two of them ended abruptly half an inch or so from the disk. The other had almost vanished.

"What happened?" I asked.

"Antibiosis," he said. "The first, of course, was a dud. Here's how it works. It's really quite a simple test. As you can see, the procedure isn't unlike the one we use in plating out soil samples. Only, in this case we inoculate the medium with bacteria. That's what those ditches are. They're cultures of different pathogens. The kind depends on what diseases we happen to be interested in at the moment. If we're looking for an antibiotic of potential usefulness against tuberculosis, we'll use a selected strain of *Mycobacterium tuberculosis*, and so on. I don't know just what things English is testing for right now—they vary from time to time—but a representative selection might include the typhoid organism, one of the staphylococci, something in the field of urinary-tract infection, a pneumococcus, a meningococcus, and possibly a *Hemophilus pertussis*, the whooping-cough bug. As you probably know, those are all bacteria. The tests for anti-viral activity are run off in another laboratory. They involve the use of infected chick embryos instead of plate cultures, but I'm not going to attempt to describe them. They're much too complicated. The same goes for the rickettsiae, only more so. In addition, they're extremely risky. We don't even do them. No house does. All our screening for rickettsial activity is done for us by the Harvard Medical School. But to come back to bacteriology. When the bacterial cultures are well established, we dip a round of filter paper—one of those disks there—in a flask of broth containing a mature growth of mold and set it out on the dish. If the mold is capable of producing an antibiotic, it will be present in the broth, and the filter paper will soak up all we need. That's one of the most remarkable characteristics of an antibiotic—its high specific activity. Of course, to be effective, all drugs must be able to withstand a good deal of dilution without loss of potency. But the antibiotics are unique in that respect. Some organisms are sensitive to some antibiotics in solutions containing as little as one part antibiotic to one hundred million parts of diluent. That's what makes a test like this possible. Otherwise, the almost immeasurably minute amount of antibiotic substance present in that little disk could never have had the effect you see on the cultures in those three ditches. One culture practically wiped out and two very definitely in-

hibited. Unfortunately, a sight like that is pretty rare. Only about five per cent of our molds show any promising kind of antibiotic activity. The rest turn out exactly like that other—nothing." He picked up the covers and fitted them back on the dishes. "As a matter of fact," he added, "even some of those that do show some activity never get to the pilot plant. Biochemical analysis always eliminates a few of them. They just won't lend themselves to any kind of practical production."

We were still some distance from the pilot plant, moving down another lifeless corridor, when I caught a whiff of something sweet and damp and musty. It was a familiar smell, but for a moment I couldn't place it. Then, as we approached a heavy door at the end of the corridor, the smell grew stronger, and I remembered. It was the dark, earthy smell of a country cellar in summer. Mr. Kane saw me wrinkling my nose, and smiled. "Mold," he told me. "Or, rather, a combination of mold and broth. What you're actually smelling is fermentation. If you think this is powerful, you ought to walk by one of our main production buildings. You'd swear you were passing a distillery. A couple of months ago, a tenement over that way burned down. In the ruins, the police found the remains of a still. All the neighbors had smelled it—you can't disguise the smell of an operation like that—but apparently nobody had given it a thought. They thought it was penicillin."

Mr. Kane laughed. He opened the door, releasing a blast of pungent warmth, and waved me into a glitter of white tile, reptilian pipes, and polished metal tubs—huge, hooded, and wholly enigmatic—patrolled by a squad of men in spotless white. Several of the men had writing boards under their arms, and one was crouched at the base of a tub, staring at a panel of dials and making an occasional note. At the far end of the room, silhouetted against a wall of windows, rose three great cylindrical tanks of stainless steel. They were at least twenty feet high and perhaps five in diameter, and each was capped by a bristling growth of pipes and gauges and levers and wheels. Girdling the three tanks, some fifteen feet above the floor, was a narrow, railed catwalk, reached by an iron stairway. We emerged from the parade of hulking tubs at the foot of the stairs. "You don't often see fermentation tanks this size in a

pilot plant," Mr. Kane said, heaving himself agilely up ahead of me. "They'll hold two thousand gallons apiece. The average is around three hundred. But, compared to the tanks we use in commercial production, they're pygmies. We've got some up at Groton with a capacity of twenty-five thousand gallons. However, that's the only difference—size. These tanks and the biggest ones all operate on the same principle. John McKeen gave you a rough idea of how submerged fermentation works. If you remember, he said it involved aerating a liquid mass. Well, the air is introduced into the broth by means of a high-pressure sparger in the base of the tank. Sterile air, of course. But there's more to the problem than that. Left to itself, the mold would naturally tend to accumulate on the surface of the broth. We prevent that by a system of agitators fixed to a central vertical shaft. They keep the mass in a turmoil, and the result is growth at every level. Maybe you'd like to take a look." He indicated a small glass porthole set in the shoulder of the nearest tank. I rubbed away a film of moisture and peered in. At first, I could see nothing but darkness. Then the darkness dissolved into a murky twilight, and I could just make out a tiny fury of sand-colored foam. There was nothing else. "Disappointed?" Mr. Kane asked as I straightened up. "I always am. Too much like a washing machine."

"How much antibiotic does a tank this size produce?" I asked.

"That depends," Mr. Kane replied. "It's largely up to the mold. As you know, some are heavier producers than others. We'll seed one of these tanks with anywhere from two ounces to five gallons of pure culture. The incubation period varies, too. A few molds will produce their maximum of antibiotic in a couple of days. Others need a week. I'd say the average return from a two-thousand-gallon tank is about nine pounds. We don't necessarily recover that much, though. There's almost always some loss during extraction. Those machines down there on the floor are all extractors of one kind or another. I'm going to give you the simplest possible notion of that phase of our operation. The procedure is roughly this: When the antibiotic has been excreted into the broth, we pump the whole mass of material out of the tank and through a rotary drum filter. That separates the liquor from the mold. Then the mold

is discarded and the liquor is piped through a series of centrifugal extractors, each containing a different chemical solvent, which eliminates by absorption certain extraneous matter. At the end of six or, seven passages, we're left with a fairly pure concentrated solution of antibiotic and water. We run that through another filter, this time for the purpose of sterilization, and then an evaporation tank. The result is a bucket of more or less colorless crystals. It's also either the end or the beginning. That's when we find out what we've got."

We were standing at the catwalk rail, looking down at the men and machines on the floor below. For a moment, neither of us spoke. Then Mr. Kane turned toward the stairs. As we passed the tank whose contents I had glimpsed, he put out a hand and lightly brushed its flank. It was an odd, caressing gesture. "You never know," he said. "All you can do is hope. We seeded this tank this morning with a mold that—well, to put it mildly, it looks like a wonder. It looks even bigger than terramycin. In other words, it's just possible that with fifty-seven million square miles of earth to choose from, we've been lucky enough to pick up the prize handful. But, as I say, you never know." He gave me a rueful smile. "It's also very possible," he said, "that all we've done is rediscover streptomycin."

Poliomyelitis

Without a doubt, the medical story of 1953-55 was the development of the Salk polio vaccine. Poliomyelitis is not really a common disease. It can, however, be uncommonly nasty when it occurs. Moreover, polio is among the virus diseases for which no effective means of treatment is at hand or in sight. It can be dealt with only by preventing it with an immunizing vaccine. Hence, the Salk vaccine is an achievement of solid importance.

Below are two key documents on its development. One is (in abridged form) the historic paper in which Dr. Salk, professor of preventive medicine at the University of Pittsburgh, reported to fellow physicians and scientists his first successes in immunizing children against polio. The paper, reprinted by permission of the American Medical Association and Dr. Salk, appeared in the *Journal of the American Medical Association* for March 28, 1953. Four of Dr. Salk's associates—Maj. Byron L. Bennett, Drs. L. James Lewis and J. S. Youngner, and Miss Elsie N. Ward—collaborated with Dr. Salk in preparing this report.

You will find it interesting and rewarding, if not easy, reading. It tells not only what Dr. Salk did, but shows how medical research is conducted. There are a few points, though, to be kept in mind as you read. First, the simple watery vaccine that did not seem too effective to Dr. Salk at first has since been greatly improved, and is the vaccine now in use. Second, in developing a vaccine, the trick is to grow the microörganism responsible for a disease (in this case, polio virus), and then kill or treat it in some way so as to make it incapable of causing disease, but to retain its "antigenicity," or capacity for stimulating the body to form the defensive antibodies that make one immune against the disease. In developing a vaccine, it is necessary to measure frequently the concentrations of virus and of antibodies. Virus and antibody con-

centration is generally referred to in scientific papers, like Dr. Salk's, as virus and antibody "titer." Finally, details of the killing procedure and of safety and potency tests have been changed from those reported in this paper.

The second document is a synopsis of the famous Francis report on the 1954 field trial of the Salk vaccine—the largest medical field trial ever undertaken. The report itself was prepared by Dr. Thomas Francis, Jr., a world-renowned authority on vaccines and virus diseases and director of the Poliomyelitis Vaccine Evaluation Center at the University of Michigan. The synopsis printed here was prepared by Dr. Robert F. Korns, deputy director of the center.

JONAS E. SALK

Studies in Human Subjects on Active Immunization Against Poliomyelitis

Investigations have been under way in this laboratory for more than a year, with the objective of establishing conditions for destroying the disease-producing property of the three types of poliomyelitis virus without destroying completely their capacity to induce antibody formation in experimental animals. The success of experiments in monkeys with vaccines prepared from virus produced in tissue culture and referred to briefly elsewhere led to the studies now in progress in human subjects. It is the purpose of this report to present the results obtained thus far in the investigations in man. . . .

Approaches to Artificial Immunization

Among the earliest reports on immunization of monkeys and then of man were those of Brodie and of Kolmer in the early

1930's. Their studies were conducted before precise knowledge regarding pathogenesis and immunologic complexity were available, and before there had accumulated the vast experience with the many strains that possess different pathogenic characteristics. Moreover, methods had not been developed for adequate purification of virus from suspensions of central nervous system tissue, nor were the dynamics of virus inactivation or modification well enough understood.

More than a decade later, Morgan clearly demonstrated that a formaldehyde-treated suspension of central nervous system tissue from monkeys containing a type 2 strain of poliomyelitis virus did, after a rather rigorous schedule of immunization, induce the formation of appreciable quantities of antibody. She was also able to induce a measurable degree of resistance to intracerebral challenge in monkeys vaccinated repeatedly with similarly prepared type 1 virus.

Other investigators in studies with mice and cotton rats confirmed the fact that preparations of type 2 virus that were noninfectious were still capable of inducing immunity in rodents. Thus, it would appear that materials devoid of demonstrable infectious activity for animals will immunize if given repeatedly in sufficient amount. . . . The question that still remains is how antibody formation may be induced in a practicable manner. . . .

Material and Methods

Source of Virus for Vaccine.—The vaccines employed in these studies were prepared from virus propagated in roller tube cultures of two different tissues derived from monkeys. Monkey rather than human tissue was decided on for producing the virus for these experiments in human subjects because of the remote possibility that human tissue might occasionally be contaminated with such agents as the virus of infectious hepatitis that might conceivably propagate in cultures of human tissue. . . .

Although testicular tissue was the first monkey tissue used for culturing the virus, it appeared desirable to investigate other monkey tissues for comparison. Enders and associates had

employed such human sources as the foreskin, embryonic skin and muscle, the kidney, and the uterus. It seemed of interest, therefore, to explore cultures of monkey kidney and muscle, which are available in much larger supply than testicular tissue. . . . The advantage of the testicular cultures in yielding virus for long periods [was found to be] offset by the greater abundance of virus in kidney cultures in the early days after virus inoculation. This example is presented to illustrate why the decision was made to use kidney rather than any of the other tissues in further studies on vaccines. . . .

In the search for a fluid medium free of protein and still satisfactory for maintaining the viability of the tissues and for supporting virus multiplication, it was soon found that the chemically defined mixture no. 199 described by Morgan, Morton, and Parker and first used for similar studies by Rhodes and his associates, provided such a nutrient fluid. This mixture consists of a large number of amino acids, certain nucleic acid constituents, vitamins, and minerals, as well as other essential growth-promoting or growth-sustaining substances. . . .

Selection of Strains.—For preparing the vaccines to be used in these investigations, strains were selected quite arbitrarily and principally on the basis of the regularity with which they could be propagated in relatively high titer [concentration] in tissue culture. It is highly probable that substitutions will be made for certain of the strains now in use as further information is gathered in regard to the characteristics most desirable for inclusion in a vaccine.

The strains selected to represent types 1, 2, and 3, respectively, are known as the Mahoney, MEF-1, and Saukett strains. . . .

Destruction of Infectivity.—Prior to chemical treatment for destruction of infectivity, the culture fluids were first clarified by centrifugation and then stored in an electric deep freeze (at approximately —20° C). Before preparation for vaccine, the fluids were thawed, centrifuged until crystal clear, pooled, and then treated with formaldehyde.

On the basis of the results of numerous experiments, the details of which will be presented elsewhere, the decision was

made to use 0.4% of a 37% solution of formaldehyde U.S.P. This reagent is commonly referred to as "formalin." Virus inactivation was allowed to proceed at the temperature of melting ice (approximately 1° C). The consideration that led to this decision was that at low temperatures the action of formaldehyde is relatively slow and might, thereby, be more selective in destroying infectivity without impairing too greatly the antigenic activity of the virus. . . .

Mention should be made of the observation that different periods of treatment with formaldehyde were required for eliminating infectivity of the different preparations studied. It appears that the type 3 strain (Saukett) was the most sensitive in this respect, with the MEF-1 (type 2) and Mahoney (type 1) strains more resistant in that order. Whether these observations mean there are qualitative differences among strains in their sensitivity to inactivation by formaldehyde or whether what has been observed is a function of virus concentration remains to be determined. . . .

[Two kinds of vaccine were prepared from these viruses by Dr. Salk. One contained formaldehyde-killed virus and water. The other contained formaldehyde-killed virus in a water-and-oil emulsion.—Ed.]

Safety Tests.—The first problem that had to be resolved before human subjects could be inoculated was the question of safety. It has been the consensus that tests for safety should include the intracerebral inoculation of monkeys. In all of the material employed for human beings, the absence of infectivity for the cynomolgus monkey was established in prior tests by the intracerebral inoculation of 0.5 ml. of fluid in six to ten animals. As an additional safeguard, the only preparations considered satisfactory for use were those that had been exposed to the action of formaldehyde for at least 24 to 48 hours after the test just described indicated that infectivity had been destroyed. The fact that amounts of virus that produce paralysis when given intracerebrally are not paralytogenic when given intramuscularly or intravenously suggests that the intracerebral safety test may provide a more than adequate margin in certifying a given preparation as safe for use in human subjects. . . .

Human Subjects

In extending to man studies on vaccination performed in laboratory animals, tests on more than a few individuals had to be anticipated. The first persons to participate in these studies were patients paralyzed in recent years by a poliomyelitis infection and who were in residence at the D. T. Watson Home for Crippled Children, Leetsdale, Pa. In addition to patients who had recovered from paralytic poliomyelitis, there were others who were in residence at the Watson Home for such diseases as arthritis, spastic paralysis, and a variety of congenital deformities. After the initial investigations were under way at the Watson Home, additional studies were undertaken at the Polk State School, Polk, Pa. . . .

Of the group of 98 patients at the Watson Home, 51 are participating in studies involving aqueous vaccines inoculated intradermally, and 27 are involved in studies on emulsified vaccines given intramuscularly. All of the 63 individuals at the Polk State School have been given emulsified vaccines intramuscularly . . .

Experimental Procedures and Results

The principal purpose of the experiments to be described was to determine whether or not the experimental vaccines that were made could induce antibody formation in human subjects. In the initial explorations, small doses of aqueous vaccines were inoculated intradermally. From the studies completed thus far, the indications are that only the type 2 preparation then available was effective when administered in this way. Later experiments were performed with experimental vaccines emulsified in mineral oil and inoculated intramuscularly. In these studies it was found that antibody for all three types was induced. . . .

1. *Aqueous Vaccines Inoculated Intradermally.*—The subjects involved in these experiments had been paralyzed, one or more years earlier, by acute poliomyelitis. The vaccines employed were made from tissue culture fluids treated with for-

maldehyde, as indicated in the section on methods. . . .

In the experiment designated W-2, 0.1 milliliter [about .1 cubic centimeter] of each type was inoculated into three separate sites on the volar aspect of the forearm. Six weeks after the first inoculation a second dose of vaccine was given. This part of the study was designated as W-5, and the types 1, 2, and 3 fluids selected for this inoculation had been treated with formaldehyde for 10, 13, and 10 days respectively. . . .

Antibody Response to Type 2 Vaccines Formaldehyde-Treated for 13 Days:—The postvaccination blood samples here recorded were taken in the 11th week after the first dose, or the 5th week after the second dose. . . . In 25 of the 27 subjects no type 2 antibody was demonstrable before vaccination and in all instances the titer rose to levels of from 1:8 to 1:256. The two who had antibody before vaccination also responded with a rise in titer. It is evident . . . that a four-fold or greater rise in antibody titer developed in all 27 . . . [In 11 individuals] antibody titers are available four and a half months after the initial inoculation, and in none is there any indication as yet of fall in the level of antibody induced by vaccination. . . .

Comments on Results of Studies With Aqueous Vaccines.—In experiments of the kind just described, it is necessary to be certain that the immunologic changes attributed to vaccination are not caused by natural infection in the populations under study. It was for this reason that a group of controls was used to test this factor, and the results of studies in this group show no indication that rises in type 2 antibody occurred in this population within the interval of observation.

In concluding these remarks about the experiments on intradermal inoculation with preparations treated with formaldehyde, it is desired to point out that the very distinct rise in antibody that occurred following intradermal inoculation of the type 2 preparation was not paralleled in the subjects similarly inoculated with the types 1 and 3 preparations employed at the same time. The type 1 preparation that had been treated with formaldehyde for 10 days (Mahoney pools 7, 11) exhibited some antigenic activity in many subjects; however, the serologic tests have not been repeated in all instances and, therefore, are not ready for presentation at this time. There

was no indication of any antigenic activity in the type 3 fluid that had been treated with formaldehyde for 10 days. The tentative conclusion that has been drawn is that the effectiveness of the type 2 (MEF-1 pool 15-K) preparation may be related to the presence of a greater concentration of virus in the starting fluid before treatment with formaldehyde, and that this may have been due to the fact that this pool was derived from cultures of kidney rather than testicular tissue. The latter was used in preparing the types 1 and 3 pools, which were the only ones available at the time these experiments were undertaken. Further study will indicate whether these differences are related to concentration of virus in the respective pools, or to qualitative differences among strains with respect to their sensitivity to formaldehyde.

2. *Emulsified Vaccines Inoculated Intramuscularly.*—In planning the experiments at the Polk State School, as an extension of the early studies at the D. T. Watson Home, it seemed that the first question that needed an answer was whether or not antigenic activity could be demonstrated when formaldehyde-treated fluids of all three immunologic types are incorporated together and emulsified with mineral oil. If it were possible to show that such preparations induced antibody response to all three types, an attempt would be made in the next phase to answer the question as to the relative efficiency of virus emulsified with mineral oil, as compared with similar or larger doses administered without mineral oil and inoculated via different routes, i.e., intradermally, subcutaneously, and intramuscularly.

In the first study carried out at the Polk State School, a group of 16 subjects were inoculated with [emulsified] vaccine no. 2, [containing type 1 virus treated with formaldehyde for 7 days; type 2 treated with formaldehyde for 10 days; and type 3 virus treated with formaldehyde for 7 days.]

Each tissue culture fluid was emulsified separately with an equal quantity of oil and was pretested for sterility before the three types were blended by mixing 4 ml. of each together with 8 ml. of mineral oil to disperse the rather thick emulsion. A dose of 1 milliliter of this mixture was given intramuscularly; it contained 0.1 ml. of the formaldehyde-treated tissue culture

fluid for each type, and the total quantity of tissue culture fluid in the 1 ml. dose was 0.3 ml.

Titration data for type 1 antibody before and after vaccination are available in 15 of the subjects, for type 2 antibody in 12, and for type 3 antibody in all 16. . . . [It was found that a rise in antibody titer for type 1 occurred in 13 of 15 subjects two to four weeks after vaccination; for type 2, in 10 of 12 subjects two to four weeks after vaccination; and for type 3, in 13 of 16 subjects four to seven weeks after inoculation. Thus, the three immunologic varieties of poliomyelitis virus appear antigenic when incorporated in a vaccine containing all three immunologic types.—Ed.]

Comment

Antibody Levels Resulting From Vaccination and Natural Infection.—In order to obtain some idea of the relationship of level of antibody induced by vaccination to that resulting from natural infection, antibody titers for all three immunologic types were studied in recently paralyzed patients; this was also done in a group of persons with no prior history of paralytic poliomyelitis. . . . Following vaccination it appears [from data omitted here] that the distribution of antibody titers compares well with those of recently paralyzed patients. . . .

Theoretical and Practical Implications

From the theoretical viewpoint, the findings presented are of interest because antibody responses occurred following inoculation with quantites of material that *a priori* might not have been expected to be effective. . . .

Comparative data on the antibody-inducing effect in humans of poliomyelitis virus vaccines with and without emulsification with mineral oil are meager. However, the trend in the observations here reported is in keeping with the results of studies with influenza virus vaccines, in which it has been found that a concentration of virus in sodium chloride solution, just below the threshold necessary to induce antibody formation, can be rendered antigenically effective if prepared in a water-in-oil

emulsion. The efficacy of this method for inducing antibody formation with small quantities of antigen has been discussed elsewhere. When a sufficient concentration of influenza virus is emulsified with mineral oil and inoculated into experimental animals, it has been possible to evoke the formation of much greater concentrations of antibody than develop as a result of experimentally induced infection. Similar observations are being accumulated in studies with the poliomyelitis virus.

Another consideration to which it is desired to draw attention is the use of cultures of kidney tissue that yield, as compared with other tissues, relatively high concentration of virus into the fluids that bathe the cultured tissue. This may have been a significant factor in providing not only a rich source of virus but one relatively free of extraneous protein or other potentially antigenic material. The absence of significant amounts of tissue material, other than the virus itself, may have played a role in favoring the demonstration of the antigenic potentiality of the chemically treated virus preparations. For example, it has been found, in experiments not yet reported, that admixture of central nervous system tissue suspension with influenza virus markedly inhibits the formation of antibody specific for the influenza virus, when such a mixture is emulsified with mineral oil and inoculated into experimental animals. When influenza virus without central nervous system tissue is emulsified with mineral oil, the full potentiality of the antibody-producing effect of the virus is evident. It would appear from this observation, which confirms findings made many years ago by Laidlaw in studies with distemper virus, that the relatively small amount of virus in proportion to the total amount of extraneous tissue mass present in brain or cord suspension might be relatively ineffective antigenically merely because of the blocking of antibody-producing "space" by the nonviral elements, and not because of the absence of antigenic capacity of the virus itself.

All of the subjects included in the experiments here described possessed, prior to inoculation, antibody for one or another of the virus types. This is emphasized since it is conceivable that the immunologic response of such individuals even to virus for which they possess no detectable antibody may be different from that of persons who have no antibody for any type and

are first brought into contact with the poliomyelitis virus when inoculated with vaccine. The answer to this question will soon be forthcoming. In fact, it appears from preliminary results in [two] experiments that antibody formation, for type 2 virus at least, occurred in six young subjects with no demonstrable antibody for any type before vaccination. . . .

From the practical point of view, it is noteworthy that antibody formation has been induced in man with the very small volumes of tissue culture fluid used here. It would appear that the problem of producing a sufficient quantity of virus, even for the purpose of a noninfectious vaccine that might conceivably be used on a large scale would not be limited so long as a tissue is employed that would yield virus in a concentration not less than that present in the fluids used in these studies. In this same regard, it may be that the mineral oil may not only render effective a preparation that would not have been antigenic without emulsification but, in addition, may permit a given quantity of material to be extended further, if fluids with greater virus concentrations can be produced. It would seem from the results of the present studies with the small quantites of fluid employed that preparation of enough virus for vaccine would not be impractical even if tissue culture fluids had to be concentrated tenfold. . . .

Summary and Conclusions

Preliminary results of studies in human subjects inoculated with different experimental poliomyelitis vaccines are here reported. For preparation of these vaccines virus of each of the three immunologic types was produced in cultures of monkey testicular tissue or monkey kidney tissue. Before human subjects were inoculated, the virus was rendered noninfectious for the monkey by treatment with formaldehyde.

In one series of experiments it appears that antibody for all three immunologic types was induced by the inoculation of small quantities of such vaccines incorporated in a water-in-oil emulsion. In another series of experiments, antibody formation was induced by the intradermal inoculation of aqueous vaccines containing the type 2 virus. Information at hand indicates that

the antibody so induced has persisted without signs of decline for the longest interval studied thus far, i.e., four and a half months after the start of the experiment.

Levels of antibody induced by vaccination are compared with levels that develop after natural infection. The data thus far available suggest that it should be possible with a noninfectious preparation to approximate the immunologic effect induced by the disease process itself.

Although the results obtained in these studies can be regarded as encouraging, they should not be interpreted to indicate that a practical vaccine is now at hand. However, it does appear that at least one course of further investigation is clear. It will now be necessary to establish precisely the limits within which the effects here described can be reproduced with certainty.

Because of the great importance of safety factors in studies of this kind, it must be remembered that considerable time is required for the preparation and study of each new batch of experimental vaccine before human inoculations can be considered. It is this consideration, above all else, that imposes a limitation on the speed with which this work can be extended. Within these intractable limits every effort is being made to acquire the necessary information that will permit the logical progression of these studies into larger numbers of individuals in specially selected groups.

Poliomyelitis Vaccine Evaluation Center,
University of Michigan

Evaluation of 1954 Field Trial of Poliomyelitis Vaccine

Synopsis of the Francis Report

During the spring of 1954 an extensive field trial of the prophylactic effectiveness of formalin-inactivated poliomyelitis vaccine, as developed by Dr. Jonas Salk and his associates, was initiated by the National Foundation for Infantile Paralysis.

The Poliomyelitis Vaccine Evaluation Center was established at the University of Michigan for the purpose of impartially collating and analyzing data collected through the combined efforts of many thousands of health department workers, practicing physicians, physical therapists and laboratory people scattered through the 211 participating study areas in 44 states.

The study design was dictated by both scientific and practical considerations, necessary in a project of such scope and dependent on the good will and abilities of so many people of varying capacity. They involved the organization and execution of the vaccination clinic program, the maintenance of detailed and accurate records, as well as the thorough investigation, according to a detailed plan, of each reported case of poliomyelitis in the area. Originally, it was deemed impractical to establish a strict placebo control experiment, with the complex administrative problem of giving three injections in sequence to each child, without knowing the nature of the material being used. Thus, all states were invited to participate on the basis of administering vaccine to volunteers in the 2nd grade of school. Later the poliomyelitis incidence in these children would be compared with that in the uninoculated 1st and 3rd grade population. This study plan had certain scientific limitations, related primarily to possible bias, at all levels, in the follow-up of study children. Obviously it was essential that nonvaccination children be studied with the same degree of care as the vaccinated so that the discovery and diagnosis of cases of poliomyelitis in

test and control groups would be strictly comparable. In order to achieve such an impartial comparison it was essential to introduce a so-called placebo control study into the existing plan. This type of study was carried out in 84 areas of 11 states signifying the interest in doing so. In 127 areas of 33 states the original, or observed control, study was carried out. The specific study areas were selected because of their consistently high poliomyelitis incidence during the past 5 years.

The tremendous clinic program was accomplished according to plan during April, May and June. In placebo control areas the study population (1st, 2nd and 3rd grade) included 749,236 children; 455,474 (or 60.8%) requested participation; 200,745 (26.8%) received three injections of vaccine, and 201,229 (26.9%) three injections of placebo, an identical material which, however, contained no poliomyelitis virus or monkey kidney protein. In observed control areas the study population totaled 1,080,680 children in the first three grades; 221,998 second grade children (20.5% of the total) received three doses of vaccine.

The first problem of evaluation was that of collecting and verifying basic information on each of the 1,829,996 children in the study population. These data, which included the name, address, age, sex, history of polio or other crippling condition, participation status and dates of vaccination, if any, for each child, were transferred to punch cards, and tables describing the population were prepared which would serve as the denominators over which the discovered cases of polio would be placed for the determination of polio attack rates in vaccinated vs. control and in other segments of the population. During December, 1954, an interview survey was conducted on 1,100 study families in ten states in order to gain more insight into the differences existing between participants and nonparticipants. This demonstrated striking differences in income level, community activity, health conveniences, education level, etc., which in turn assisted the center in deciding what control population would be most useful, in the observed control areas.

The question of safety of the vaccine was assessed through specific studies of the cause and extent of absenteeism from school following inoculation in Pittsburgh and Schenectady,

N. Y. The experience was identical in vaccinated and control subjects and no significant reactions were observed. From records obtained during the clinic program, the following distribution of minor reactions was observed: Placebo control areas—931 reactions or 0.4% in vaccinated and 939 or 0.4% in those receiving placebo. Of the so-called "major" reactions, none of which could be clearly attributed to inoculation, 9 or 0.004% occurred in vaccinated and 13 or 0.006% in the placebo control. These findings, plus other data referred to in the text, fail to implicate the vaccine as a significant cause of untoward reactions.

Also bearing on the question of safety is the review of 129 cases occurring up to the first month after inoculation. Here again, there is no evidence implicating vaccine as a source of infection. Furthermore, study of the location of the paralysis failed to demonstrate any localization of involvement to the left arm, where all injections were given.

For the purpose of measuring the antigenic potency of the various lots of vaccine used, blood samples were collected prior to vaccination, 2 weeks after the 3rd clinic and again 5 months later from 40,881 children. Results from the study of sera from 9,000 of these are now available for analysis and served as the basis for classifying lots of vaccine into good, moderate, low moderate, and poor categories. There was wide variation in the response to various lots, as used under field conditions. In general, the response to Type 1 polio virus was inferior to that for Types 2 and 3. Data from the study of the third bleeding are less complete but indicate some persistence of antibodies 4 to 5 months after completion of the series of vaccinations. Some decline in antibody titer was observed, particularly in those children vaccinated with so-called poor lots; however, the levels in vaccinated children persisted in being distinctly higher that in the associated control children.

The second problem in evaluation was concerned with the discovery and investigation of all cases of poliomyelitis or suspected poliomyelitis in the study population. The various steps in the investigation are discussed at length in the report, but consisted essentially in the initial case report; a clinical epidemiological report; muscle evaluation by one of 67 spe-

cially trained physical therapists 10 to 20 days and 50 to 70 days after onset of illness; the review of these findings by clinical experts; and the laboratory study of stool and blood samples from the patient, for the isolation of poliomyelitis or other virus and the search for poliomyelitis antibodies. An important phase to all the above studies and applying particularly to the work of the physical therapists and laboratories was the attempt to standardize the procedures used in all areas, so that the findings would be directly comparable in all segments of the study. Finally, rigid criteria were established for reaching the final diagnosis. Each study case was finally classified before the vaccination status was revealed, thus assuring unbiased interpretation of all data.

Results

The comparison of the poliomyelitis attack rate in vaccinated and control populations is presented through a sequence of steps, each one attempting to purify further the diagnosis. A total of 1,013 cases was reported in the study population with onset during the period two weeks after the third vaccination clinic to December 31, 1954. These are classified in placebo control areas as follows: 67.5% paralytic, 17.6% nonparalytic, 7.2% doubtful, 7.6% not polio.

As a first step, the total reported cases, total cases considered to be polio, total nonparalytic and total paralytic in both placebo and observed control areas were examined. Through these stages of purification there is a progressive increase in the percentage of effectiveness displayed. No significant difference was detected in the rates of nonparalytic poliomyelitis in test and control groups. However, when these cases and those called not polio are removed, so that only paralytic cases remain, an estimate of 75% of effectiveness is obtained in the placebo areas, and 62% in the observed areas.

Next more detailed attention was given to the effect of vaccine with respect to clinical type and extent of paralysis. The most striking effect was observed in bulbospinal disease, perhaps because this characteristic clinical pattern is so readily differentiated as being truly poliomyelitis. In this group, the

estimate of effectiveness in placebo control areas was 94% with a lower limit of 81%. The effect noted in spinal paralytic polio was less striking, 60% with a lower limit of 39%. In observed control areas, these differences were even less pronounced but still highly significant.

A further refinement in analysis was to consider the effect of vaccine in patients from whom poliomyelitis virus was isolated. These furnish a higher degree of confidence in diagnosis. In cases classified as spinal paralytic, the effectiveness was the same in placebo and observed control areas, 82% and 83% respectively, and the corresponding lower limits of effect were 65% and 64% respectively. Enforcement of laboratory criteria for diagnosis apparently eliminated a substantial number of cases which were less influenced by vaccination, and, undoubtedly among them, were many illnesses which actually were not poliomyelitis. The effect in bulbospinal polio, with laboratory confirmation superimposed, was 91% in placebo control and 60% in observed control areas.

The next step was to examine the effect of vaccine with reference to the specific type of poliomyelitis virus isolated. In placebo control areas the effectiveness was 68% against Type 1, 100% against Type 2 (significant at .05 level), and 92% against Type 3. This clearly agrees with the previous demonstrations that most lots of vaccine were less antigenic against Type 1 than against the other two types. In addition, the effectiveness of different lots of vaccine varied considerably as measured by the occurrence of poliomyelitis.

From these data it is not possible to select a single value giving numerical expression in a complete sense to the effectiveness of vaccine as a total experience. If the results from the observed study areas are employed, the vaccine could be considered to have been 60 to 80% effective against paralytic poliomyelitis, 60% against Type 1 poliomyelitis, and 70 to 80% effective against disease caused by Types 2 and 3. There is, however, greater confidence in the results obtained from the strictly controlled and almost identical test populations of the placebo study areas.

On this basis it may be suggested that vaccination was

80 to 90% effective against paralytic poliomyelitis; that it was 60 to 70% effective against disease caused by Type 1 virus and 90% or more effective against that of Type 2 and Type 3 virus. The estimate would be more secure had a larger number of cases been available.

Other Studies

Several supplemental analyses are presented in the body of the report, which have bearing on evaluation and are mentioned briefly here.

1) The effectiveness of vaccine in preventing cases of poliomyelitis classified by extent of paralysis on the basis of the first muscle examination was compared with that, based on the second muscle examination, which in essence, measured the extent of residual paralysis. This later group demonstrated a much more striking preventive effect, which becomes more distinct as the severity of the disease increases.

2) Study of the polio attack rate by individual years of age in test and control groups serves to confirm the other observations on effectiveness, although in placebo control areas the difference seen in six-year-old children was not statistically significant. There appears to be a progressive increase in effect as age increases, based on the limited data and narrow age span included in this study.

3) The poliomyelitis experience in the study areas of Massachusetts and central N. Y. State is subjected to detailed analysis since the reported disease in these areas was extremely mild and doubt exists as to whether many of the illnesses are due to poliomyelitis. Of the 44 cases reported from Massachusetts polio virus was recovered from only three. Unidentified, or so-called "orphan viruses" were recovered from 31. A somewhat similar experience occurred in central N. Y. State. In these areas the effect of vaccine was much reduced or difficult to detect. The role of the "orphan" viruses in causing illness has not been established and needs further study.

4) The studies carried on in Canada and Finland were limited in scope and differed somewhat in design. However, despite the small number of cases of poliomyelitis occurring in study

children, a significant preventive effect was demonstrated on refined analysis.

5) A major activity in the field trial areas was the investigation of all cases of poliomyelitis, where a study child resided in the household. Analysis of these data in placebo control areas indicates that among the 233 vaccinated children exposed to a case of poliomyelitis in the family, only 1 developed a laboratory confirmed illness, a Type 1 infection (0.43%). On the other hand, among 244 children who had received placebo and were exposed under similar circumstances, 8 developed laboratory confirmed poliomyelitis (3.28%). This is a statistically significant difference. This was not correspondingly distinct in the observed study areas.

6) Although it was urged that gamma globulin not be used in the study population during the course of these investigations, inevitably some was used for measles and hepatitis prophylaxis and for both family contact and mass application in connection with poliomyelitis. Records of this use were collected and the tabulation indicates that during the period May 1 to December 31, in placebo control areas, only 0.9% of the vaccinated children and 1.1% of those given placebo received some gamma globulin.

In observed control areas the use was even less, 0.4% in both the test and control groups. No matter what one believes about the practical effectiveness of gamma globulin in preventing poliomyelitis, the total use of this material and its equal distribution in vaccinated and nonvaccinated children, indicates that it did not interfere with proper evaluation of the effectiveness of vaccine. . . .

W. GREY WALTER

A Mirror for the Brain

One of the most useful means of peering into the brain is the study of "brain waves," the rhythmic electric currents generated by the brain. Electroencephalography (as their recording and study is termed) has yielded a wealth of information on the functioning of the brain. It is also an everyday essential in the diagnosis and treatment of epilepsy, brain tumors, brain injuries and many other disorders involving the brain.

"A Mirror for the Brain" is an account of the development of electroencephalography by one of its great pioneers, Dr. W. Grey Walter of the Burden Neurological Institute, Bristol, England. The account is taken from the chapter of the same name in Dr. Walter's recent book, *The Living Brain*. The reprint, together with illustrations, is by permission of the publishers, W. W. Norton & Company, Inc., and Gerald Duckworth and Company, Ltd., of London. A number of minor insertions (all clearly indicated) have been made in the abridgment in the interest of clarifying it for American readers.

It took a war to bring the opportunity of devising a technique for exploring the human brain—and two more wars to perfect it. Two medical officers of the Prussian army, wandering through the stricken field of Sedan, had the brilliant if ghoulish notion to test the effect of the Galvanic current on the exposed brains of some of the casualties. These pioneers of 1870, Fritsch and Hitzig, found that when certain areas at the side of the brain were stimulated by the current, movements took place in the opposite side of the body.

That the brain itself produces electric currents was the discovery of an English physician, R. Caton, in 1875.

This growing nucleus of knowledge was elaborated and carried further by Ferrier in experiments with the "Faradic current." Toward the end of the century there was a spate of information which suggested that the brain of animals possessed electrical properties related to those found in nerve and muscle. Prawdwicz-Neminski in 1913 produced what he called the "electrocerebrogram" of a dog, and was the first to attempt to classify such observations.

The electrical changes in the brain, however, are minute. The experiments of all these workers were made on the exposed brains of animals. There were no means of amplification [of electric currents] in those days, whereby the impulses reaching the exterior of the cranium could be observed or recorded, even if their presence had been suspected. On the other hand, the grosser electrical currents generated by the rhythmically contracting muscles of the heart were perceptible without amplification. Electrocardiography became a routine clinical aid a generation before the invention of the thermionic [vacuum] tube made it possible to study the electrical activity of the intact human brain. . . .

The first occasion on which the possibilities of clinical electroencephalography were discussed in England was quite an informal one. It was in the old Central Pathological Laboratory at the Maudsley Hospital in London, in 1929. [A year before, Dr. Hans Berger of Berlin had reported detecting rhythmic electric currents generated by the brain.—Ed.]

The team [at Maudsley Hospital] under Professor Golla was in some difficulty about electrical apparatus; they were trying to get some records of the "Berger rhythm," using amplifiers with an old galvanometer that fused every time they switched on the current. Golla was anxious to use the Matthews oscillograph, then the last word in robust accuracy, to measure peripheral and central conduction times. I was still working at Cambridge under the watchful eye of Adrian and Matthews and was pleased to introduce this novelty to him and at the same time, with undergraduate superiority, put him right on a few other points. When, at lunch around the laboratory table, he referred to the recent publication of Berger's claims, I readily

declared that anybody could record a wobbly line, it was a string of artifacts, even if there were anything significant in it there was nothing you could measure, and so on. Golla agreed with milder skepticism, but added: "If this new apparatus is as good as you say, it should be easy to find out whether Berger's rhythm is only artifact; and if it isn't, the frequency seems remarkably constant; surely one could measure that quite accurately." And he surmised that there would be variations of the rhythm in disease.

Cambridge still could not accept the brain as a proper study for the physiologist. The wobbly line did not convince us or anybody else at that time. Berger's "elektrenkephalograms" were almost completely disregarded. His entirely original and painstaking work received little recognition until in May, 1934, Adrian and Matthews gave the first convincing demonstration of the "Berger rhythm" to an English audience, a meeting of the Physiological Society at Cambridge.

Meanwhile, Golla was reorganizing his laboratory, and his confidence in the possibilities of the Berger method was growing. When he invited me to join his research team as physiologist at the Central Pathological Laboratory, my first task was to visit the German laboratories, including particularly that of Hans Berger.

Berger, in 1935, was not regarded by his associates as in the front rank of German psychiatrists, having rather the reputation of being a crank. He seemed to me to be a modest and dignified person, full of good humor, and as unperturbed by lack of recognition as he was later by the fame it eventually brought him. But he had one fatal weakness: he was completely ignorant of the technical and physical basis of his method. He knew nothing about mechanics or electricity. This handicap made it impossible for him to correct serious shortcomings in his experiments. His method was a simple adaptation of the electrocardiographic technique by which the electrical impulses generated by the heart are recorded. At first he inserted silver wires under the subject's scalp; later he used silver foil bound to the head with a rubber bandage. Nearly always he put one electrode over the forehead and one over the back of the head; leads were taken from these to an Edelmann galvanometer, a

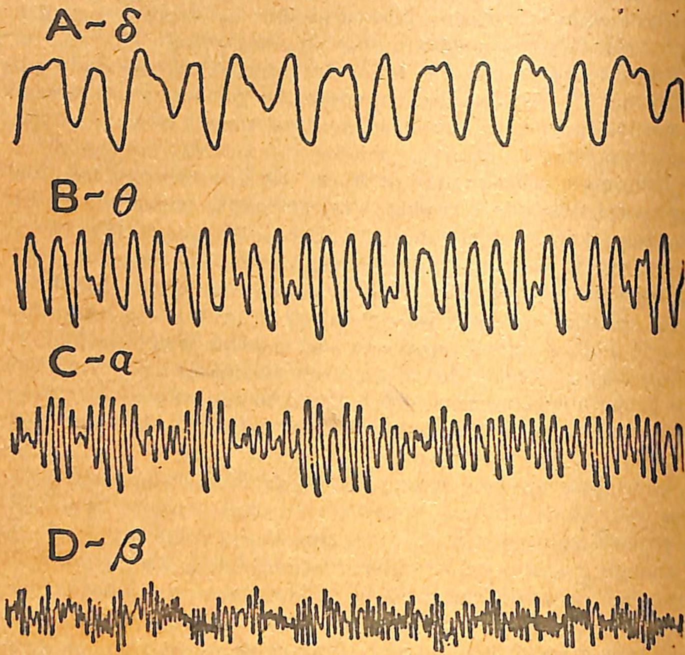
light and sensitive "string" type of instrument, and records were taken by an assistant photographer. A potential change of one-ten-thousandth of a volt—a very modest sensitivity by present standards—could just be detected by this apparatus. Each record laboriously produced was equivalent to that of two or three seconds of modern continuous pen recording. The line did show a wobble at about 10 cycles per second. He had lately acquired a tube amplifier to drive his galvanometer, and his pride and pleasure in the sweeping excursions of line obtained by its use were endearing.

Berger carried the matter as far as his technical handicap permitted. He had observed that the larger and more regular rhythms tended to stop when the subject opened his eyes or solved some problem in mental arithmetic. This was confirmed by Adrian and Matthews with leads from electrodes on Adrian's head attached to a Matthews amplifier and ink-writing oscillograph. This superior apparatus, and a more careful location of electrodes, enabled them to go a step farther and prove that the 10 cycles per second rhythm arises in the visual association areas in the occiput and not, as Berger supposed, from the whole brain.

Only some years later was it realized what an important step this was. Its significance could not be recognized while so little was known about the components of the "wobbly line," the electroencephalogram or, abbreviated, EEG. Unavoidably at the time, the significance of the salient character of the normal EEG was overlooked; it was found, in Adrian's phrase, "disappointingly constant." The attention of many early workers in electroencephalography therefore turned from normal research to the study of nervous disease. In immediate rewards this has always been a rich field. In this instance, a surprising state was soon reached wherein what might be called the electropathology of the brain was further advanced than its electrophysiology.

In the pathological laboratory, Golla's earlier surmise, that there would be variations of the rhythmic oscillation in disease, was soon verified. A technique was developed there by which the central point of the disturbance in the tissue could be accurately determined. For surgery, the immediate result of perfect-

ing this technique was important; it made possible the location of tumors, brain injuries, or other physical damage to the brain.



". . . the frequency of a rhythm is more significant than its amplitude . . ." Records showing the main wave-forms found in EEGs. (A) Delta—0.5 to 3.5 cycles per second. (B) Theta—4 to 7 c/s. (C) Alpha—8 to 13 c/s. (D) Higher Frequency (Beta)—14 to 30 c/s.

It was helpful in many head cases during the war as well as in daily surgical practice.

The study of epilepsy and mental disorders also began to occupy the attention of many EEG workers. The difficulties encountered in these subjects threw into prominent relief the

essential complexity of the problem as compared with those of classical physiology. The hope of isolating single functions had now been abandoned; those who entered this field were committed to studying the brain as a whole organ and through it the body as a whole organism. They were therefore forced to multiply their sources of information.

It is now the general EEG practice, not only for clinical purposes, but in research, to use a number of electrodes simultaneously, indeed as many as possible and convenient. The standard make of EEG recorder has eight channels. Eight pens are simultaneously tracing lines in which the recordist, after long experience, can recognize the main components of a complex graph. The graphs can also be automatically analyzed into their component frequencies. A more satisfactory method of watching the electrical changes in all the main areas, as in a moving picture, a much more informative convention than the drawing of lines, has been devised at the Burden Neurological Institute. This will be described after a simple explanation of what is meant by the rhythmic composition of the normal EEG; for its nature, rather than the methods of recording and analyzing it, is of first importance for understanding what follows.

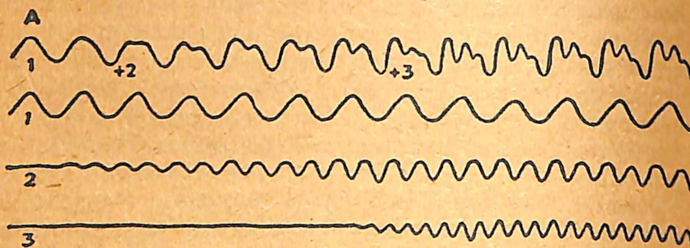
If you move a pencil amply but regularly up and down on a paper that is being drawn steadily from right to left, the result will be a regular series of curves. If at the same time the paper is moving up and down, another series of curves will be added to the line drawn. If the table is shaking, the vibration will be added to the line as a ripple. There will then be three components integrated in the one wavy line, which will begin to look something like an EEG record. The line gives a coded or conventional record of the various frequencies and amplitudes of different physical movements. In similar coded or integrated fashion the EEG line reports the frequencies and amplitudes of the electrical changes in the different parts of the brain tapped by the electrodes on the scalp, their minute currents being replayed by an amplifier to the oscillograph which activates the pens.

All EEG records contain many more components than this; some may show as many as twenty or thirty at a time in significant sizes. Actually there may be tens of thousands of impulses

woven together in such a manner that only the grosser combinations are discernible.

A compound curve is of course more easily put together than taken apart. (See Illustration.) The adequate analysis of a few inches of EEG records would require the painstaking computation of a mathematician—it might take him a week or so. The modern automatic analyzer in use in most laboratories writes out the values of twenty-four components every ten seconds, as well as any averaging needed over longer periods.

The electrical changes which give rise to the alternating cur-



Here is a compound wave (top line) formed from three simple wave curves (below). Actual EEGs have many more component waves and have a much more complex form.

rents of variable frequency and amplitude thus recorded arise in the cells of the brain itself; there is no question of any other power supply. The brain must be pictured as a vast aggregation of electrical cells, numerous as the stars of the Galaxy, some ten thousand million of them, through which surge the restless tides of our electrical being, relatively thousands of times more potent than the force of gravity. It is when a million or so of these cells repeatedly fire together that the rhythm of their discharge becomes measurable in frequency and amplitude.

What makes these million cells act together—or indeed what causes a single cell to discharge—is not known. We are still a long way from any explanation of these basic mechanics of the brain. Future research may well carry us, as it has carried the

physicist in his attempt to understand the composition of our atomic being, into vistas of ever increasing enchantment but describable only in the convention of mathematical language. Today, as we travel from one fresh vista to another, the propriety of the language we use, the convention we adopt, becomes increasingly important. Arithmetic is an adequate language for describing the height and times of the tides, but if we want to predict their rise and fall we have to use a different language, an algebra, with its special notation and theorems. In similar fashion, the electrical waves and tides in the brain can be described adequately by counting, by arithmetic; but there are many unknown quantities when we come to the more ambitious purposes of understanding and predicting brain behavior—many *x*'s and *y*'s; so it will have to have its algebra. The word is forbidding to some people; but, after all, it means no more than "the putting together of broken pieces."

EEG records may be considered, then, as the bits and pieces of a mirror for the brain, itself *speculum speculorum*. They must be carefully sorted before even trying to fit them together with bits from other sources. Their information comes as a conventional message, coded. You may crack the code, but that does not imply that the information will necessarily be of high significance. Supposing, for instance, you pick up a coded message which you think may be about a momentous political secret. In the first stage of decoding it you might ascertain that the order of frequency of the letters was ETAONI. This does not sound like very useful information; but reference to the letter-frequency tables would assure you at least that it was a message in English and possibly intelligible. Likewise, we watch the frequencies as well as the amplitude and origin of the brain rhythms, knowing that many earnest seekers for the truth have spent lifetimes trying to decipher what they thought were real messages, only to find that their horoscopes and alembics contained gibberish. The scientist is used to such hazards of research; it is only the ignorant and superstitious who regard him, or think he regards himself, as a magician or priest who is right about everything all the time.

Brain research has just about reached the stage where the letter frequencies of the code indicate intelligibility and their

grouping significance. But there is this complication. The ordinary coded message is a sequence in time; events in the brain are not a single sequence in time—they occur in three-dimensional space, in that one bit of space which is more crowded with events than any other we can conceive. We may tap a greater number of sectors of the brain and set more pens scribbling; but the effect of this will only be to multiply the number of code signals, to the increasing embarrassment of the observer, unless the order and interrelation of the signals can be clarified and emphasized. Redundancy is already a serious problem of the laboratory.

The function of a nervous system is to receive, correlate, store, and generate many signals. A human brain is a mechanism not only far more intricate than any other but one that has a long individual history. To study such a problem in terms of frequency and amplitude as a limited function of time—in wavy lines—is at the best oversimplification. And the redundancy is indeed enormous. Information at the rate of about 3,600 amplitudes per minute may be coming through each of the eight channels during the average recording period of twenty minutes; so the total information in a routine record may be represented by more than half a million numbers; yet the usual description of a record consists only of a few sentences. Only rarely does an observer use more than one-hundredth of one per cent of the available information.

"What's in a brain that ink may character . . . ?"

For combining greater clarity with greater economy, many elaborations of methods have been adopted in clinic and laboratory. They still do not overcome the fundamental embarrassment of redundancy and the error of oversimplification, both due to the limitations of a time scale. A promising alternative is a machine that draws a snapshot map instead of a long history, projecting the electrical data visually on a spatial coordinate system which can be laid out so as to represent a simple map or model of the head. This moving panorama of the brain rhythms does approximate to Sherrington's "enchanted loom where millions of flashing shuttles weave a dissolving pattern, always a meaningful pattern though never an abiding one."

We have called the apparatus which achieves this sort of effect at the Burden Institute a toposcope, by reason of its display of topographic detail. The equipment was developed by Harold Shipton, whose imaginative engineering transformed the early models from entertainment to education. Two of its twenty-four channels are for monitoring the stimuli; the others, instead of being connected with pens, lead the electrical activity of the brain tapped by the electrodes for display on the screens of small cathode-ray tubes. So instead of wavy lines on a moving paper, the observer sees, to quote Sherrington again, "a sparkling field of rhythmic flashing points with trains of traveling sparks hurrying hither and thither." Assembled in the display console, twenty-two of the tubes give a kind of Mercator's projection of the brain. Frequency, phase, and time relations of the rhythms are shown in what at first appears to be a completely bewildering variety of patterns in each tube and in their ensemble. Then, as the practiced eye gains familiarity with the scene, many details of brain activity are seen for the first time. A conventional pen machine is simultaneously at the disposal of the observer, synchronized so that, by turning a switch, a written record of the activity seen in any five of the tubes can be made. Another attachment is a camera with which at the same time permanent snapshot records of the display can be obtained.

Thus, from Berger's crude galvanometer to this elaborate apparatus requiring a whole room of its own, electroencephalography has progressed from a technique to a science. Its clinical benefits, by-products of free research, are acknowledged; they can be gauged by the vast multiplication of EEG laboratories. From Berger's lone clinic have sprung several hundred EEG centers—more than fifty in England alone. Literally millions of yards of paper have been covered with frantic scribblings. In every civilized country there is a special learned society devoted to the discussion of the records and to disputation on technique and theory. These societies are banded together in an International Federation, which publishes a quarterly journal and organizes international congresses.

For a science born, as it were, bastard and neglected in infancy, this is a long way to have traveled in its first quarter of

a century. If it is to provide the mirror which the brain requires to see itself steadily and whole, there is still a long road ahead. Looking back, we realize that the present scale of work as compared with previous physiological research is elaborate and expensive. But our annual cost of conducting planned investigations of a fundamental nature into man's supreme faculties is less than half that of one medium tank, and the money spent on brain research in all England is barely one-tenth of one per cent of the cost of the national mental health services.

WILLIAM C. MENNINGER

Psychoanalytic Psychiatry

No volume pretending to cover even the main developments in modern science would be complete without an account of the ideas and work of Sigmund Freud. However, partly because many of his ideas still seem novel, partly because psychiatry employs an impossible jargon, clear accounts of what Freud found and believed are hard to come by. The article here is one of the very few. It is abridged from one of a series of lectures given by Dr. William C. Menninger at Cornell University in 1947 under the Messenger foundation, and is reprinted from *Psychiatry: Its Evolution and Present Status* by Dr. Menninger, with the permission of Dr. Menninger and the Cornell University Press. Dr. Menninger himself needs no introduction. He and his brother Karl are widely known for the Menninger Clinic at Topeka, Kansas, an institution that has made Topeka one of the main centers of psychiatry in America.

The use of the term "psychoanalytic psychiatry" implies that there are other brands or types of this science. Historically this is true. There were and still are those who approach psychiatry as if all mental illness could be treated as an organic nervous disease problem. There are others who are quite content with practicing a psychiatry of description, merely noting the constellation of symptoms and classifying them without seeking to understand the meaning of the illness or giving specific treatment. Psychoanalytic psychiatry is synonymous with dynamic psychiatry, and its fund of knowledge dates from the truly great discoveries of Freud, which began in 1890. It is the only psychiatry that has formulated theories of anatomy and of the

physiology of the personality.

Though some persons express disagreement with some of Freud's observations and conclusions, they do so in most instances without having carefully studied his original reports. Even psychiatrists who are critical have accepted and obviously utilize much more of Freud's contribution than they seem to recognize. . . .

Regardless of our personal or scientific opinions of Freud and his work, many of us feel that through his stimulus psychiatry was given a new birth. It was converted from a purely descriptive science, largely preoccupied with psychoses, into a dynamic, rational system capable of serving as a basis for interpreting psychopathology. Such interpretations are applicable to the acts of everyday behavior as well as to the great variety of human illnesses described as neurotic reactions.

It may be helpful for the sake of orientation to amplify the meaning of the word *psychoanalysis*. Psychoanalysis was the term employed by Freud initially to refer to a method of treatment. It is still used in this sense to identify a technique that is applicable in a very limited number of personality disturbances. In the process of using it as a treatment, however, Freud accumulated an enormous amount of material. As he attempted to evaluate and classify his data, he developed a psychological theory. As a consequence, when one speaks of psychoanalysis, he may refer to this psychological theory. The term "psychoanalysis" also refers to a research technique. Obtaining data by a process of clearing away, stratum by stratum, the abnormal psychic material is a process Freud likened to the excavation of a buried city. In both instances the find was apt to prove surprising, and emphatically so in the case of psychoanalytic investigation. All three of these features, namely, a method of treatment, a psychological theory, and an investigative procedure, have continued to be characteristics of the total process of psychoanalysis. . . .

I shall attempt to present in an extremely condensed fashion four of the major areas of psychoanalytic psychiatry that contribute most to the understanding of behavior: the psychosexual stages of development, the anatomy of personality in terms of the conscious and unconscious, personality physiology in terms

of the Id, Ego, and Super-Ego, and, finally, some examples of the defense mechanisms used by the Ego to maintain its equilibrium.

Psychosexual Development

One of the most significant discoveries of psychoanalysis was that the events of infancy and babyhood are all-important in shaping the personality or character of the individual. Psychoanalysis turned the spotlight, perhaps, better, the telescope, on this area of development and has shown without question or doubt that it is during these early years that the basic personality structure and patterns of behavior are laid down. It is during this period that the groundwork is laid for later mental health or ill health. Since this experience occurs during a period for which the adult has amnesia, he is completely unable to explain certain attitudes or behavior in himself.

Freud's study and evaluation of the data he had gained in the treatment of his patients indicated to him that there were definite stages in infant and child personality growth and psychosexual development.

With the introduction of the term "psychosexual," additional explanation is in order. One of the most frequent criticisms of psychoanalysis is that it is too much occupied with sex. Critics are unaware, however, of the fact that to Freud the term "sex" meant far more than genital activity. It included all forms of physical gratification. Moreover, few of these critics know that every psychiatric patient under intensive psychological treatment always brings up this subject himself. The treatment of patients led to the discovery that seeking for gratification is an instinctive drive in every person and cannot be ignored because of prudishness any more than can any other instinctive need. Even as the term is used in America, sex is one of the basic and all-pervasive motivations in life. Furthermore, everyone has some minor or major difficulties concerned with sexual life at various crucial periods of development—during adolescence, at marriage, or at other times when adjustment must be made to associates or spouse. Sexual maladjustment is accepted, even by nonpsychoanalytic psychiatrists, as a major causative factor

in mental illness. In any case, the misunderstanding is due both to semantic differences and to the suppression and repression of this basic human interest and activity. The result has been much resistance to the initial acceptance of psychoanalysis both as a body of knowledge and as a treatment technique. Incidentally, the American cultural taboo against discussion of this instinctual need is a significant factor in the high incidence of neuroses.

Growing up entails changing from a little animal concerned only with his own physical processes into a social being cognizant of relationships between himself and other people. This change starts in the first year of life. Very early the inherent internal forces within the child, namely, his will to live, to express himself, and to find gratification, must be integrated with his surroundings, his environment, his parents, his siblings, and the external world. It is through the initial and early experiences in the family that the child learns to relate himself to people and to develop certain techniques by which he accomplishes this.

When the infant is born into the world, we can be sure that he has no interest except selfishly to gratify his own cravings. He has certain instincts at birth, and the demand to satisfy these is his only motive in life. In his early months the infant gives nothing to anyone else; he makes no attempt to please anyone; in short, he is interested only in receiving what he wants. One may say that he follows the path of gaining all the pleasure he can and so far as possible avoiding displeasure and pain in any form. . . .

It is only after some years that the child begins to apply what is known as the "reality principle," namely, the acceptance of a limited amount of pain or unhappiness or dissatisfaction because of the promise of more gratification in the future. It is one of the changes that must occur in order for the child to become an adult psychologically.

During the first three, four, or five years of life the child has three experiences that are of paramount interest to him and through which he formulates his relations to those about him. Continuing through most of his first year is his interest in and his gratification from nursing (sucking). This is his chief con-

tact with the external world and with those about him, and it serves as his chief source of satisfaction.

Toward the end of this year a new interest appears. Through the efforts of his parents to encourage his control of his excretions, the child's attentions become focused on those processes. They become his chief bodily interest and in some degree replace the previously primary interest in using his mouth.

Between the second and third year the child's interest turns to curiosity about his or her sexual organs and their function, how they differ from those of others. Concurrent with and related to the interest in this new area of physical gratification, is a new type of relationship to his parents and siblings.

The child passes imperceptibly from one phase to another in his development; no lines of demarcation separate one period from another. Nevertheless, it is possible to outline the various characteristics in each of these stages. The evolution of growth through these periods is referred to as psychosexual development. It is psychical development because it has to do with forms of psychological gratification. It is sexual development because it concerns various parts of the body that serve as sources of gratification. It will be apparent that the word "sexual" in this connection is obviously a much more inclusive term than laymen ordinarily consider it. . . .

The Unconscious

The second major contribution of psychoanalytic psychiatry to the understanding of behavior is a concept of the anatomy of the personality as being divided into a conscious and an unconscious portion. None of us have clear recollections of those experiences in infancy that occurred during psychosexual development. Thus none of us have any real knowledge of the basis of many of our most outstanding personality traits—honesty or dishonesty, sociability, selfishness or unselfishness, and so forth. The average individual usually believes that he knows why he does all that he does. Sometimes, however, his explanations for his attitudes and behavior are so shallow that he himself may question their validity. Occasionally he may admit that he does not know just why he does a certain thing or why he takes a

certain point of view. Human behavior is complex, and the average person has no explanation why one individual has a persistent fear of crowded places or another has frank delusions. The same would puzzle the psychiatrist without a theory of the existence of a major part of the personality—the unconscious—that motivates much of our behavior.

Originally, as the explanation of neurotic behavior, Freud postulated the existence of a large area in the individual's personality that was not under voluntary control. In his early definition of the theory he tried to explain neurotic symptoms as resulting from the interaction of forces, some of which obviously arose from a deep, unrecognized layer of the personality and others of which stemmed from a conscious level of the personality. In order to develop a functional concept, he made a topographical division of the personality into a conscious and an unconscious system. The chief source of symptoms was the conflict between the forces resident in each system. "The outcome of this conflict depended upon the economic relationship between these two sets of forces, yet the sum of the two psychic forces could practically always be considered constant." This simple theory was later amplified by Freud himself into a much more complicated one in order that he might take into account many additional factors, both within and without the personality, that he believed determined behavior.

By definition, the psychiatrist regards the unconscious as a large region of the mind that is inaccessible to conscious awareness by ordinary means of questioning or self-examination. In it are contained the inherited and racial trends. This region of the mind contains the basic energy drives. In the very small infant they are allowed free expression without restraint and without modification. As the child grows up, the primitive expressions of these drives have to be molded, cloaked, and controlled, but they remain the sources of energy. The unconscious also contains the no longer consciously remembered learning experiences of infancy and early childhood as well as all the associations established at that time.

The unconscious cannot be demonstrated like the brain, for it is not an anatomical unit. It is a concept whereby behavior can be explained. There is much evidence to support the prem-

ise of such a functional portion of the personality, perhaps the most convincing of which can be demonstrated in the process we call hypnosis. Hypnosis is a form of suggestion by which certain individuals can be placed in a trancelike state, subject to the control of the hypnotist. In this state of mind an individual may recall incidents or remember facts that he is not able to recall normally. During this trance the hypnotist can make suggestions to be carried out after the person has emerged from the hypnotic state and without the person's recalling that these acts were suggested to him.

Another very common type of evidence of the existence of the unconscious is one's dreams. Some popular opinion may regard them as nonsensical and meaningless. Nevertheless, scientifically they are recognized as a kind of thought process, which is specific for the dreamer. They always have a significant relationship to the thought process of his conscious life. The dream is a production of the unconscious part of the mind that is censored and altered before reaching the conscious part. It is usually so disguised that the average individual cannot recognize its true meaning. . . .

Recall of forgotten experiences under special conditions is another evidence of the unconscious. Only under certain circumstances can we recapture the memory of them. This is a most important phenomenon, however, because certain long-forgotten infantile and childhood experiences must be recalled in the effective treatment of some mental illnesses.

The psychoanalytic concept regards the unconscious as a powerful force in the life of every individual and not as an inert group of discarded experiences or associations. The unconscious is present at birth and exists throughout life, always remaining primitive and infantile. In other words, it is the conscious part of us that matures while the unconscious remains the same from babyhood to old age. Not only does it contain inherited instinctual drives, but it also receives many of the unaccountable interests, desires, and experiences that we must repress, that is, exclude from our conscious personality. Into the unconscious of every individual must go the erotic satisfactions of infancy, the forbidden hostile feelings toward parents and siblings, and many other unsocial wishes and even

behavior that the mature adult personality cannot accept as a part of his conscious life.

The Id, Ego, Super-Ego Relationship

The division of the personality into conscious and unconscious levels does not completely explain human emotions, thought, and behavior. A further elaboration of the psychoanalytic theory describes these conscious and unconscious regions as having three functional and interrelated systems, each of which has certain characteristics and functions. Each is dependent to some degree on the others, the Id, the Ego, the Super-Ego. . . .

The Id. The Id is that portion of the personality that constitutes most of the unconscious region. It makes up the whole of the personality at birth. The Id remains unrefined throughout life and is that part of the individual referred to popularly as "the animal in man." It has no regard for morals; it never learns or acquires what we think of as intelligence. It never "grows up"; it changes little from birth to adulthood except through the additions of certain experiences that the conscious part of the individual refuses to keep in its own house and so forces into the domain of the Id. Its only rule of existence is to seek pleasure and avoid pain, regardless of consequences.

Its function, if we may call it such, is to supply the psychic energy that the person uses in life, the will to live. Freud was sufficiently discerning to distinguish two directions or aims of motivation in the expenditure of psychological energy. He identified these as "instincts," using the term to refer to an unconscious, impelling drive toward a particular type of behavior. He believed that these two drives were related to each other and that, under ideal circumstances of adjustment, they would interact in such a way as to neutralize the overt, primitive expressions of each other. One of these instincts impels the individual toward aggressive, destructive, or hostile behavior. The other impels the individual toward erotic, constructive, or affectionate behavior.

Both of these instincts or drives are manifest in the behavior of everyone. The relationships established by one person with

other people and with objects, as well as all forms of behavior, can be identified as expressions of these two motivating pressures. As suggested, the ideal adjustment implies a fusion of the aggressive and affectionate elements within the personality. When sufficiently blended with a constructive, affectionate instinct, the aggressive element loses its hostile, destructive element. When there is a failure in the fusion, one sees the direct expressions of hate and destruction.

In our culture the expressions of these drives are expected to be modified, directed, or deflected into acceptable social behavior. At best, however, the conscious ego can exert only a somewhat superficial control, so that one's ideas and action may give minor and major evidences of the predominance of either constructive or destructive impulses in a particular personality at a particular time. These drives may be vented or invested externally or turned in toward the self. In their external expressions they are constantly modified by the environmental situation. The resulting changes in the balance of the forces within the individual and between him and the outside world are the dynamic factors in personality development.

A recognition of the presence of these drives as dynamic forces is important, but even more important is an understanding of their evolution. This evolution follows a similar pattern in everyone. The drives are modified by parental training, by developmental experiences, and by the many other contacts with the external world. In the infant most of the time the two antagonistic drives are so fused as to neutralize each other. Their energy is directed almost completely toward himself. As the world begins to intrude into his life with its irritations and frustrations, he expresses hostile aggression toward it. Through growth and training, if given love, the individual learns to merge the hostile with the erotic instinctual drives in order to react with toleration, and under suitable conditions to return affection. Some of the initial irritations he may absorb; others he may elude; still others he will change with his acquisition of experience and knowledge so that they cease to be irritating. As the child grows, more and more of his energy is directed away from himself and invested in the objects or the people he encounters in his environment. His reaction to them may be either

hostile and aggressive or erotic and affectionate, or it may be neutral.

Individuals vary in the success with which they are able to deflect the direction of this energy from themselves to the external world. Some retain a considerable investment of the erotic drive in themselves, as manifested in many expressions of self-love. Others retain a considerable degree of investment of the aggressive drive in themselves as manifested in the neuroses, the psychoses, and many other forms of partial and even complete self-destruction. . . .

It is apparent then that the power of the Id is a continuous threat to the Ego. When any impulse arising within the Id is blocked in its outlet by the Ego, tension arises and is felt as anxiety.

The Ego. It is the Ego that becomes aware of anxiety because it makes up the bulk of the personality that we refer to as "consciousness." Most of it is conscious, and it represents the thinking, knowing, and feeling part of the person. The Ego begins to develop at birth, in contrast to the Id, which already is well developed at that time. As one learns from experience and gains in knowledge, the Ego expands and grows strong or is weakened, depending on those environmental factors, particularly the parents, that assist in the solution of childhood problems.

The Ego has numerous functions. It serves as the intermediary between the world, the environment outside the individual, and the inner demands, wishes, and desires that originate in the Id. Thus its first function is to make the primitive drives of the Id conform to the demands of reality. Its guiding rule, so long as it is healthy, is to accept and to modify reality. It has the function of organizing the mental processes in a coherent fashion. It has the responsibility of obtaining gratification and satisfaction from the environment. It must control and govern the crude, though superior strength, of the impulses which come from the deep unconscious. It must mold these so that they are acceptable to the world outside the personality. It must prohibit the direct expression of desires that are self-destructive or that would destroy the environment.

Even when one goes to sleep, the Ego still censors any thought

processes that go on, and so one's nocturnal mental activity is forced to express itself in bizarre, distorted forms that we call dreams.

The Ego also controls all voluntary motor functions. A part of the Ego is unconscious, and through this portion of it all repression is carried on, along with other mental mechanisms (to be discussed later), without our being consciously aware of them.

The Super-Ego. The Super-Ego, the third system of the personality, is chiefly unconscious. It begins to develop in the individual during the third or fourth years as a means of partially solving the conflict in orienting himself to his parents. By developing a Super-Ego, the little child borrows strength from his parents through identification with them. He sets up an inhibiting force, a kind of police force within himself, a conscience, which keeps saying to the Ego, "You must not." Within his Super-Ego he has absorbed those standards of control presented to him by parents and teachers.

Thus the Super-Ego is both a conscious and an unconscious conscience, a critic that watches the conscious Ego deal with the strivings of the Id. When the Ego makes poor decisions, including those with which the conscience cannot agree, the Super-Ego criticizes and condemns the Ego. For instance, when one wrongs a friend, he feels remorse in proportion to his understanding of the degree or extent of his aggressions against the friend. His Ego feels guilty and seeks punishment, so that he feels he needs to make restitution. The critical Super-Ego may force him to make excessive efforts toward restitution, which may be expressed in various kinds of self-punishment, self-failure, and self-depreciation. . . .

The Ego is the intermediary between the Id and Super-Ego and the external world. It must harmonize three powerful forces, that is, the Id, the Super-Ego, and Reality, all of which are potentially stronger than it is.

Sometimes the Ego is unable to conform to reality, that is, the external world; sometimes it is not sufficiently strong to adjust the personality to the demands of the external situation. When it is so threatened, symptoms develop; the soldier in combat frequently develops physical disturbances of his heart

or his stomach. Others react by denying the reality situation by the formation of delusions or other types of falsification of the true environmental situation.

Again, if the Ego is sufficiently strong, it either holds the demands and impulses of the Id in check or modifies them into some form of expression that is socially approved. Sometimes the Ego remains loyal to reality, but the primitive wish puts on a masquerade and so disguises itself that it gains expression without the Ego's recognizing it as the forbidden desire. When this occurs, the resulting expression may be a socially approved sublimation or a neurotic symptom. When the Ego is weak, it may permit certain of these primitive impulses to gain direct expression as we see them in psychoses or antisocial behavior. . . .

The equilibrium of the Ego is threatened continuously from all sides. When the Ego weakens or begin to fail in its function, the individual shows the symptom of anxiety. In order to avoid anxiety the Ego develops certain devices that we call "dynamisms," or "mechanisms" that help maintain the equilibrium between these three portions of the personality. They serve as a medium of expression of the Id impulses that can be accepted by external reality. These mechanisms are a necessary part of the functional equipment of the Ego of every person, and they constitute one of the most widely accepted and most helpful portions of psychoanalytic psychiatry.

Mental Mechanisms

A slowly developing conscious Ego can control, guide, and modify the unconscious instinctual energy with only varying degrees of success. There is no one who does not experience an occasional serious maladjustment, nor are any of us completely free of eccentric or unusual traits of character and behavior. Everyone shows neurotic symptoms at one time or another. Complete control of the primitive expressions of energy is not possible all the time and under all circumstances. Psychiatric patients continuously display grossly uncontrolled or only thinly masqueraded expressions of energy that are exaggerations of the pathological behavior of everyday life.

The mental mechanisms are the devices that the personality uses, both in health and in sickness, to channel its unconscious drives. Their expressions are always apparent and conscious, but they originate in the unconscious. Therefore, their stimulus as defenses against tension induced by conflict within the personality is an automatic attempt to control the expression of primitive energy. They are not consciously activated. Once recognized, their action may be modified by a conscious decision to do so. Knowledge of these mechanisms gives us an understanding, not only of illogical behavior and ideation, but also of normal behavior. . . .

It is neither possible nor practical to discuss all these mechanisms in a brief space. Quite deliberately five of the more common have been selected for brief presentation as illustrative examples.

One of the most common mental mechanisms is *sublimation,* the device by which we obtain gratification through the channeling of primitive energy into some type of socially approved activity. Sublimated expressions provide a healthy release of the same instinctual energy that produces symptoms in the sick individual who cannot sublimate or repress it. Although individual capacity for sublimation varies widely, much of the activity of our daily life represents this mechanism. Sublimation is always healthy, and when the individual fails to use it, he invariably displays symptoms. Thus the original aggressive drive, instead of being manifested in its raw forms of hate and destruction, is converted by sublimation into leadership, initiative, and healthy aggressiveness. All of us maintain a reservoir of hostility. In the well-adjusted individual this is drained off through many of our activities, such as a competitive athletic contest or digging in the garden or playing bridge. . . .

Rationalization is a second type of mechanism that we all use frequently. Technically speaking, it is the device for explaining plausibly and thus accounting for or justifying certain feelings, ideas, or behavior. The explanation always appears to us a logical one.

All of us at times believe that our mistakes or blunders are the result of fate. We explain our feelings on the basis of the weather. When we do not do something we should, we justify

our action; when we want something badly, we find good reasons for getting it. Rationalization does not refer to consciously concocted explanations but rather to apparently honest and logical thought about our attitudes and our behavior. Rationalizations may be used to justify erroneous opinions or ideas. Strong loves and hates, whether they are rational indulgences or frank prejudices, are always supported by what seem to be logical explanations. The drug addict rationalizes the reasons why he must take drugs; the deluded patient explains quite rationally to himself the reasons for his delusions. The alcoholic is sincere in his belief that he began drinking to escape his troubles or his sorrow. In general we defend our position by rationalization. . . .

Another common mechanism is *displacement*. This is a process by which the emotional value attached to one idea or person is transferred to another idea or person. The emotional attitude expressed is either out of proportion or unrelated to the object toward which it is directed.

Whenever we misplace the blame or credit for a feeling that we have, we use the mechanism of displacement. Thus the upbraiding of the roommate at the end of a hard day of classes may be a displacement of hostility toward an exacting professor. The excessive lavishing of affection on a dog may be a displacement of desire to lavish affection on some human object. An excess of anger or other emotion over any trivial incident is a displacement from emotion felt about some other situation to which it may or may not be related. When the majority of a class of students fail to make passing grades, the teacher often displaces the responsibility with a belief that the students are lazy, stupid, or eccentric. When parents fail to manage a child, they often express their sense of failure in scolding or whipping the child. . . .

Displacement is a kind of face-saving device that protects our Egos from seeing their mistakes and that shields us from the unpleasant recognition of our misdirected investments of emotion and interest.

One of the mechanisms that always indicates failing adjustment, even more so than displacement, is *projection*. This is the dynamism by which the individual, in order to protect him-

self against ideas and wishes that he cannot admit he has, projects them onto another person or object in a more or less disguised form. Even though the expressions of projection may be very mild, their use indicates a failing, or a chronically poor, adjustment.

In the latter case the individual soon acquires a reputation for his tendency to blame others for his own inadequacies. Some people always blame their partners for the mistakes in the card game; they believe they do not get the right breaks; they have the conviction that their employer, their wife, or their associates do not understand them or have been unfair to them. Unjustified suspicions are examples of projection.

By the use of this device the individual always becomes the object of attention, sometimes because of assumed persecution or sometimes by an overevaluation of ability. In either case, he believes himself to be the object of special attention and thus attributes to others an interest in and motives toward himself that are entirely false.

The extreme form of this mechanism is seen in those individuals who may on the one hand regard themselves as a special emissary from the Almighty, as a great leader, as the recipient of special God-given abilities, or on the other hand as being persecuted by the government, the FBI, the Ku Klux Klan, or some other powerful group.

Finally, another mechanism that is always a manifestation of ill health, is *conversion*. By its use the Ego channels the threatening impulse from the Id into a symbolic expression of pain, distress, or functional disorder in some part of the body. The result always is a physical symptom, either motor or sensory. In this device, as in most of the defense mechanisms, the symptom represents a compromise. The Ego denies the direct expression of the repressed wish, but the symptom is a disguised expression of this wish unrecognized by the Ego.

Minor conversions occur frequently in many of us. In most of us their appearance would not justify the diagnosis of a particular mental illness. We have stomach symptoms because of homesickness. We get a headache from some special frustration. We may develop physical symptoms either in anticipation of or as the result of a situational problem.

Conversion symptoms are most spectacularly illustrated in cases of sudden blindness, loss of voice, paralysis, anesthesia. Most of these develop under acute stress and were rather commonly seen in the combat soldier. Conversion symptoms, however, include all types of physical malfunctioning that have an emotional origin, whether this be of the stomach, heart, lungs, genital system, or other part of the body. Symptoms of this type constitute the complaints of a high percentage of patients seen by family physicians and medical specialists. Therefore, an understanding of the conversion mechanism is extremely important to all medical people.

These five mental mechanisms—sublimation, rationalization, displacement, projection, and conversion—are illustrative of the automatic devices of our mental machinery. These are methods by which the conscious Ego protects itself from the development of anxiety. They are the vehicles and modes of expression, both healthy and unhealthy, of urges or wishes that seek expression from the unconscious. They constitute the psychodynamics of the personality.

6. Tomorrow

EUGENE HOLMAN

Our Inexhaustible Resources

The rapid rise in world population in recent centuries has led to a revival of interest in the doctrine of the gloomy nineteenth-century English cleric-economist, T. R. Malthus, who asserted that world population must inevitably outrun the world's capacity to produce food and other commodities. It is certainly true that the world cannot provide sustenance for an infinitely large number of persons. It seems to me, however, that the neo-Malthusians (as Malthus's current supporters are termed) fail to take into account the advance of modern science and technology and their spread to ever wider regions of the earth. Through the application of science, man's capacity to produce is also increasing rapidly; the number of persons the earth can be made to support is very much larger than the prophets of gloom suppose. Much nearer the truth, I think, is the viewpoint expressed in "Our Inexhaustible Resources" by Eugene Holman, reprinted below by permission of the Standard Oil Company (New Jersey) from the *Atlantic Monthly*. Mr. Holman is chairman of the board of directors of Jersey Standard.

All of us who are in any way connected with natural resource industries—geologists, engineers, executives, investors—are even more concerned than most people about how fast we are using up our natural resources. These materials have a vitally important place in the pattern of human existence, and people frequently fear that we are going to run out of one or another

of them. We worry about "wasting" our resources or "exhausting" them. But I suggest that the viewpoint expressed in those terms "wasting" and "exhausting" is a partial viewpoint. I think that under certain circumstances we can forget our fears and entertain the notion of inexhaustible resources.

Let's look at the record. It shows that from earliest times men have used minerals drawn from the earth. And we see that the availability of larger numbers of minerals, in greater quantities, has progressed by a kind of steplike process.

Archaeologists have shown us that prehistoric men used axes, drills, and other implements made of flint and other hard stone. With these tools they were able to create simple societies, which in turn made possible the accumulation of knowledge about the natural world.

The Stone age developed both the instruments and the knowledge which enabled men to use certain of the softer metals, especially copper and tin. Humanity then stepped up to the Bronze age. Now man had more tools and more serviceable ones. He could fell trees faster and thus have more buildings for shelter and more vehicles for transport. He could dig deeper and fracture rock more readily. He could move more widely than before over the earth.

As the men equipped with bronze tools learned more and more about the world, humanity stepped up again—this time to an age of Iron. Now man began fashioning a really formidable array of tools. He had new power to cut, grind, hammer, and otherwise work materials. He could handle masses of material with stronger levers, wedges, pulleys, gears, hooks, eyes, and pincers.

In modern times the age of Iron has given way to the Steel age. And within our own lifetimes there has been superimposed on the Steel age what we may call the age of lightweight metals, plastics, and atomic fission.

From the Stone age to the present so great a wealth of scientific information has been amassed—most of it in the past hundred years—that we now have tools and instruments of a power and precision beyond all previous imagination. We have the means to compound, cast, and grind lenses and mirrors that permit us to peer farther than ever before into matter and into

space. We command the strength of engines whose ratio of power to weight is constantly being increased. We have machines to produce millions of glass tubes whose miraculous contents harness a stream of electrons to our service.

A notable feature of the steplike pattern of material progress is that *it has proceeded at a geometric rate.* Each successive age has been shorter than the one before it. The Stone age lasted several hundred thousand years; the Bronze age, 4,000 years; the Iron age, 2,500 years. Steel was first made in commercial quantities 95 years ago; and the past 20 years have seen material developments that are almost incredible. It is as though the stairway of advancement were composed of steps with progressively higher risers and narrower treads.

Another outstanding feature in the history of material progress is that each step has been dependent on the one before it. The use of the materials available in one period—and I emphasize that word "use"—has supported societies in which men could accumulate knowledge. Such knowledge then made new quantities and new kinds of material available.

I emphasize the fact that people used the materials available in any period so that a fallacy one sometimes finds in connection with the conservation of natural resources will be crystal-clear. This fallacy is the concept of conservation as nonuse. I am convinced that nonuse results only in hobbling progress. It will not result in more natural resources for men to use but less, because it retards the march of scientific knowledge.

Now it goes without saying that I do not advocate reckless squandering of natural resources. What I do advocate is true conservation—which is not hoarding but efficient and intelligent use.

Increasing knowledge operates in a number of ways to expand the natural resources available to us. It helps us to discover new sources of materials which we are already using and in the raw form that is currently useful to us. For example, new techniques like the use of the airborne magnetometer help us to locate oil fields. New knowledge also enables us to extract a material we are already using from raw forms which we were previously unable to process, such as iron from taconite. It also

extends supplies of the familiar materials by developing more efficient methods of use. Improved heating units, turbines, and internal-combustion engines are cases in point here. More knowledge helps us work out means of using materials which have been known but not usable—as, for example, titanium. And it discovers or makes entirely new materials that do not exist in nature, such as plastics.

I'd like to enlarge a bit on these examples and their significance. Take petroleum.

A great many new sources of oil have been discovered in just the past several years. To mention only a few, there are the Williston basin in North Dakota, the Uinta basin in Utah, and the Alberta fields in Canada, the Scurry and Spraberry fields in Texas, in addition to fields in central Sumatra, southern Iraq, and the Cretaceous fields of western Venezuela. In some of these areas, geologic explorations had gone on for years without any oil ever having been found before. In others, oil had been produced before, production had subsequently fallen off, then new horizons were tapped.

By producing and using oil we have built a dynamic oil industry and have developed the means, both financial and technical, to find more oil. We have invented methods for locating and mapping structures with greater speed and accuracy. We can select where to drill a structure with better odds of success. We can reach deeper strata. As a result, in the United States alone, there has been produced since 1938 as much oil as was known to exist in the country at that time. And despite that great withdrawal, the domestic industry's proved reserves are at an all-time high level. It's as though we started out with a tank of oil, used it all up, and had a bigger tankful left. The wisdom of optimistic men in our profession, like Wallace Pratt, is becoming daily more evident.

Besides learning more about finding underground reservoirs of crude, oilmen are also learning how to get more of the oil out of the reservoir after it has been located. We are discovering how to get maximum yield from large, highly porous reservoirs of the Middle East type, where the water table is important, as we are also learning how to get maximum yield from tricky, tight reservoirs. Repressuring, waterflooding, and other

techniques of secondary recovery are also adding greatly to the quantities of oil available for people's use. The supply of usable oil is increased also by improved practices in its transport and handling, which cut down losses.

New developments in the science of refining make possible better products. This fact, coupled with improvements in consuming devices, means that we can get more work from a barrel of oil today than we could previously. And I think we've only begun to use the energy potential in a barrel of oil.

Not only are we finding new sources of liquid hydrocarbons in the familiar raw form of crude petroleum; we will be able, when and if it ever becomes necessary, to derive liquid hydrocarbons from oil shales, tar sands, coal, and other sources not used at present.

Finally, our present use of oil and coal supports an industrial and scientific structure in which men are already learning how to apply atomic power to constructive work and may learn how to harness solar energy. Such developments, of course, would probably displace the fossil fuels in some applications, thus making them available for other use. The over-all effect would be to increase still more the total amount of energy available to humanity.

Incidentally, in connection with atomic energy, two news items which I recently noticed have a bearing on our subject. Only a few months ago it appeared that the future use of atomic energy for industrial purposes might be doubtful because of the problem of the radioactive wastes. Yet only a few weeks ago, a government official reported that the solution is in sight. What he called "atomic garbage" is apparently on the verge of being employed in such a way as to be not just harmless but actually useful.

The second story was about a new atomic plant, called a "breeder reactor," now in operation. As I understand it, the object of the process is to use uranium 235, which is rare and costly, to convert nonfissionable materials, which are abundant and cheap, into fissionable material at a faster rate than the uranium 235 itself is consumed. One of these nonfissionable materials is thorium, which previously was used chiefly in the manufacture of mantles for gaslights.

I have been considering mineral energy resources. Now let us look at the picture for metals. There are 45 metallic elements and some 8,000 alloys of those metals now in commercial use.

The world in general, and the United States in particular, is using metals at a rate never seen before. Two world wars in a quarter century and the present unhappy need to build great quantities of arms have used vast amounts of iron and copper—to name but two metals in demand. Our steel expansion program now under way calls for annual production of 120 million tons—15 million tons more than we turned out last year. And, to meet our new needs, we plan to step up our domestic production of copper (which last year was about 1.2 million tons) by 225,000 tons, and aluminum by 700,000 tons.

Can we say that what has proved true of fuels will prove true of metals? We have seen that increased knowledge has led to the discovery of new sources of energy which are seemingly unlimited. Does a comparable outcome seem likely with respect to metals?

The metals we use most—iron and aluminum—are second only to the elements of oxygen and silicon in their abundance on our planet. It has been estimated that there is at least 5,000 times as much iron ore, bauxite, and alunite in the earth's crust as the world now uses annually. Furthermore, unlike fossil fuels, most metals can be reclaimed after use and used again. In the meantime, the discovery of new sources of metal supplies and the development of techniques for making them economically available go on at a rapid pace.

It wasn't so long ago that people were worrying about imminent depletion of the 50 per cent iron-ore deposits of the Mesabi range. Today a number of steel companies are planning or building facilities, estimated to cost over three-quarters of a billion dollars, for processing taconite. Taconite deposits in Minnesota occur in a hundred-mile strip, several miles broad, and are believed to amount to 5 billion tons. The reducing plants will turn out about 1 ton of 60 per cent iron from every 4 tons of taconite.

Rich deposits of iron ore have been found in a number of countries outside the United States and are now being developed, in many cases by American capital. Labrador, Venezuela,

and Brazil, for example, are the scenes of some truly epic engineering projects. A 358-mile railroad is being cut through wilderness and wasteland to haul ore from the Ungava area in Labrador to water. At Steep Rock Lake, Ontario, 70 million tons of a lake bed are being removed in a four-year dredging operation to get at an iron deposit underneath. In El Pao, Venezuela, one of two projects in that country has been completed after fourteen years of work. Ore has to be shipped by a railroad built through jungles, and by barge to the sea on a river whose water level at the loading point fluctuates 43 feet at different seasons.

We take aluminum for granted these days. It costs currently about 18 cents a pound. Yet when the Civil War started, it sold for $545 a pound. United States production now amounts to about 800,000 tons per year, and plants under construction will almost double that figure. If it becomes necessary to find substitutes for bauxite or alunite ores, chemists seem confident they will be able to produce aluminum oxide from aluminum-bearing clays.

The first plant to extract magnesium from sea water went into operation only eleven years ago with a capacity of 9,000 tons a year. Magnesium production in the United States for 1952 is expected to exceed 100,000 tons. As for the future—there's a lot of water in the sea.

Titanium is one of our most abundant metals and has long been known. What we have not known is how to extract it from the earth's crust at a cost which would make it economic for large-scale use. Up to five years ago, titanium was used chiefly as an ingredient in paint. But it is lighter than steel, stronger than aluminum, and highly heat-resistant—hence potentially very useful. Present extraction processes are still expensive, but I have heard that a more economical method is being developed.

With almost every metal the story is repeated—of widening use, of the discovery of new sources and better methods of extraction. Here, as in other fields, research and ingenuity have been great multipliers of our natural resources.

Our supply of metals is being supplemented by other rigid materials—both old ones put to new uses and newly discovered ones. Glass, for example, is an ancient product that has been

improved in recent years to the point where it can take the place of many other substances. And it is made of materials whose supply is practically unlimited.

As for plastics—mere infants in comparison with Granddaddy Glass—there seems no limit to the possibilities of synthesizing organic compounds. A hint of some of the things to come may have been contained in a story I read only a month ago of an automobile body made of plastic and layers of glass fiber. It was claimed the body is dentproof, rustproof, and, for its weight, stronger than steel. When you consider the large fraction of our steel output that goes into auto bodies you can perhaps imagine what a successful plastic body would mean in terms of metal supply. That's especially impressive when you consider further that plastics can be made from corncobs, oat hulls, the spent fibers of sugar cane, and other materials we used to regard as waste.

These benefits are available to us as they become economically feasible, in that orderly natural development characteristic of all true technical progress. We discovered long ago that the real usefulness of any new product or process begins only when its economy in use surpasses the economy of that which it is supposed to replace. We could, for example, grow bananas at the North Pole, but the usefulness of such a project is clouded by considerable doubt.

For many years, I believe, people have tended to think of natural resources as so many stacks of raw material piled up in a storehouse. A person with this sort of picture in his mind logically assumes that the more you use of any natural resource, the sooner you get to the bottom of the pile. Now I think we are beginning to discover that the idea of a storehouse—or, at least, a single-room storehouse—does not correspond with reality. Instead, the fact seems to be that the first storehouse in which man found himself was only one of a series. As he used up what was piled in that first room, he found he could fashion a key to open a door into a much larger room. And as he used the contents of this larger room, he discovered there was another room beyond, larger still. The room in which we stand at the middle of the twentieth century is so vast that its walls are

beyond sight. Yet it is probably still quite near the beginning of the whole series of storehouses. It is not inconceivable that the entire globe—earth, ocean, and air—represents raw material for mankind to utilize with more and more ingenuity and skill.

This conception of limitless raw material is not new. It is held by a number of persons. But it is an idea certainly not familiar to people at large. I notice, though, that Dr. Lahee's recent American Petroleum Institute report is receiving wide publication. It's the one that shows that for every barrel of crude oil or cubic foot of natural gas withdrawn from the ground in 1951, two new barrels of oil or cubic feet of gas were found or developed. Perhaps the idea is getting around.

I should like to point out a corollary to this thesis. It is that the concept of unlimited raw materials does not mean that progress is simple and that Utopia is at hand. On the contrary, raw materials, no matter how vast in amount, do not become available resources until human thought and effort are applied to them. In a very real sense raw materials do not exist, they are created. We know, for example, that in a region of great mineral wealth, people can grind out their lives in poverty and misery if they do not realize the wealth exists or if they do not know how to get at it. It is use that makes it valuable. Even when the wealth is made available through technical means, the accelerating growth of populations and the enormous wastage of war are additional complications to consider.

So the march up the steps of material progress, or from storehouse to storehouse—according to which figure of speech you prefer—depends not alone on the continued expansion of scientific knowledge and on industrial daring and managerial skill, but also on political and social conditions. Those conditions in many parts of the world today are not conducive to progress. In fact, extreme nationalism, government controls and monopolies, currency restrictions, abnormal tariffs, threats of expropriation, wars and revolutions, have sealed the doors to many storehouses of useful raw materials.

The basic requirement for progress is freedom—freedom to inquire, to think, to communicate, to venture. Without these conditions, the human mind and spirit will be so shackled that

the availability of natural resources will be limited and we may exhaust the known sources of some needed material and find nothing to replace it. To the free man, all things are possible. Opportunity is the wand which can change the useless into the useful, waste into raw materials of great value, exhaustible resources into inexhaustible resources. It is the key that unlocks the greatest energy source of all—the infinite power of the human individual.

The longer I live, the more convinced I am that material progress is not only valueless without spiritual progress: it is, in the long term, impossible.

RALPH E. LAPP

Power for the Future

In the course of the past several years, I have read a good many articles on atomic power. Most, it seems to me, have missed the point by worrying too much whether atomic power would cost a mill more or a mill less than electricity from conventional sources. From the beginning, the real point about atomic power has been that it offers the world a new source of energy, which the world increasingly needs. One of the few recent discussions that sticks to this point is "Power for the Future," a chapter from Ralph E. Lapp's book, *The New Force.* The chapter is reprinted by permission of Harper & Brothers, the publisher. Mr. Lapp is a physicist who has served in several government scientific agencies (including the World War II Manhattan District, which developed the atom bomb) and who has written *frequently and forcefully* on atomic energy.

As I write this, ten years have passed since the date of the world's first chain reaction in Chicago. During these years atomic energy has emerged as a lusty, if somewhat precocious, infant and by now it should be possible to foresee its future development.

Naturally, any assessment of this new force must take into account the prevailing world climate. Continuation of the deadlock between the East and the West with more and more emphasis on atomic armament will prejudice the peacetime development of atomic energy. We shall assume that world conditions will make it possible to focus more attention upon the nonmilitary atom. So, with the stipulation that war is not taken into account, let us look at atomic energy as it may be a boon

to mankind in the future. Just what does the atom promise for the future?

Let me confess that I have no special crystal ball with which to divine the future. In fact, I have on my desk an opaque and quite ancient Chinese marble sphere to constantly remind me how murky the future is and how little the human eye can discern it. But we do have some substantial basis for making educated guesses about the long-range future of atomic energy. We have back of us ten full years of work on atomic energy and, while well over ninety per cent of our work has been of a military nature, still an enormous amount of work applicable to peacetime uses has been accomplished.

As far as it is possible to see, the real peacetime promise of atomic energy lies in the power which can be released from the atom. To be sure there will be by-products such as the radioisotopes which will find increasing and more important usefulness but the real pay-off of atomic energy will be power. This is because the atom gives the promise of power and because man is such a power-hungry creature. In 1952 the Materials Policy Commission submitted a voluminous report to the President and in it were detailed analyses of the energy resources and requirements of both this country and the rest of the world. For example, it contained the estimate that the next twenty-five years would see the demand for all fuels reach almost twice the 1950 levels. In the area of electrical power production the utilities industry estimates that by 1960 the nation's power capacity will be roughly three times what it was at the end of the last war. Commenting upon the rate of use-up of our natural fuels, the President's Commission stated:

> The time will come (in the not-too-distant future) when civilization's energy needs will outrun nature's declining store of fossil fuels available for economic use. Before this happens, ways must be found to harness economically such unconventional sources as solar and atomic energy.

Man must project his thoughts to the future and to the future increased demand for power. In a sense it is easier to look forward over a century or two than it is to try to assess the

next several decades. If the heritage that we bequeath to future generations is one of depleted fuel reserves, of dry oil wells and exhausted basic mineral deposits, then the citizens of the next century or the ones after that will curse our profligacy with nature. It is entirely possible and, indeed, probable that the greater populations of the earth only a few centuries from now will look back upon the twentieth century as the Age of Plenty when people had power to burn and raw materials to waste. With both power and materials in good supply we think of science and technology as forever on the upswing but the time can come when the rising curve will peak and start downhill. Then man's productivity will fall off and with this the world's food supply will go into the decline even as its population makes greater and greater demands upon the earth's fertility.

An obvious place for man to look for more power is the atom. He should not be unduly chagrined by the pessimism of the moment regarding the economic aspects of atomic energy or the fact that there may be no large-scale peacetime ultilization of this energy within the next decade. We know that there is vastly more energy in a lump of uranium than there is in a lump of coal—roughly two million times more. And we know that we have it within our power to unlock this energy and set it to work. We are much less certain about the amounts of uranium which exist in nature and which can be economically exploited. There may not be another huge deposit like the rich Mother Lode in the Belgian Congo but there certainly are extensive deposits of lower-grade uranium ores. Until ten years or so ago there was not much incentive to hunt for uranium. Now that this lustrous pitchblende and the highly colored minerals of uranium are so much in demand the earth's surface will be scoured to turn up even deposits yielding only a few ounces of uranium per ton of ore. New chemical techniques will make it possible to work ores which up to now have been deemed worthless and this achievement will enormously increase the reserves of uranium available in the earth.

At the present time the best estimates show that the uranium reserves are much less in their energy content than our known coal reserves. Even taking into account the possibility of utilizing low-grade ores and the probability that breeding will be

successful so that both the U-238 and U-235 fractions of uranium can be used it still appears that coal is our most bountiful supply of power. However, we must remember that our premium fuels, oil and natural gas, are being rapidly depleted. Uranium can and will substitute for these fuels in many industrial applications. It does not appear that you can count upon a uranium furnace in the basement to replace the gas or oil heating unit but, nonetheless, central station atomic power should be available well before the turn of the century.

Analyzing the impact of atomic power upon our national economy is obviously a job for skilled economists. The few who have seriously studied the over-all problem and who have not been dismayed by their brief encounters with the high potentates of atomic energy in the government do not seem to have taken a very optimistic view of atomic power. They maintain that this new power will not revolutionize the world, either socially or economically. They agree that the first use of A-power will occur in special industries like those involved in the production of glass, copper, and aluminum. My own feeling is that most economists are too conservative or take too short a focus on the problem. If we look beyond the rim of this century we should see a decided impact of atomic power upon the civilization of some countries, perhaps Russia more than others because that country has a real need for power. But it is also quite possible that atomic power may be developed early enough to help strengthen America's civilian economy when, and if, the present arms race slackens off or ends.

I believe that atomic power may be a decisive factor in locating the cities of the future. For example, since uranium power could bring abundant power to the minehead it should be possible to establish small cities near remote mineral deposits which require large amounts of power for their processing. The advent of economic A-power should go a long way toward freeing man from much of his previous dependence upon such natural facilities as proximity to waterways to assure cheap transportation of fuels and raw materials.

Furthermore, we should not overlook the possibility that atomic furnaces may provide the chemists and engineers with a new tool for entirely new chemical processing techniques.

The higher temperatures available with atomic power may make it possible to open up a brand new field of chemical engineering.

The entire program of atomic power development in this country is based upon uranium furnishing heat which is then extracted from a nuclear reactor through conventional engineering techniques. In fact it is due partly to limitations of the latter that atomic power is so slow in reaching the American scene. Now no qualified physicist believes that electricity can be won directly from the uranium atom, that is, not on any economically practical basis. But some physicists hold out hope that the heat produced in a nuclear reactor can be used in an unconventional manner without being encumbered by all the limitations of heat exchangers, turbines, condensers, and all the equipment of conventional thermal engineering. The hope is that a means may be found to utilize the heat from the atom without making this detour. Scientists have some ideas about how this can be done but as yet they have not proved practicable. This does not mean, however, that something new may not turn up. In fact, in a new field such as atomic energy the unexpected should be expected. There is always the possibility of a new discovery, even of a development as revolutionary as fission itself.

In looking to the future it is well to recognize that most scientists are extremely conservative in making any forecasts. Where they have few signposts to guide them they tend to be even more cagey about predictions. I recall that even the great Lord Rutherford, the father of experimental nuclear science, expressed the belief as late as 1937 that his studies in atomic energy would not be of practical value. Five years later the first chain reaction was achieved.

So far man has succeeded in merely scratching the surface of the energy which is locked up inside the atom. In uranium fission, for example, only one-tenth of one per cent of the atom's energy is tapped. In hydrogen fusion, only one-half of one percent of the energy is given up. In other words over 99 per cent of the atom's energy is left untapped. This is because man today is only able to get at the energy which is released by a rearrangement of the particles inside the tiny nucleus of the atom. When a uranium nucleus fissions into two smaller frag-

ments the total number of particles inside the nucleus of the parent and the daughter atoms does not change. The same is true of hydrogen fusion. Man taps only the difference in what we call the binding energies of the parent and daughter. If the particles themselves could be converted into energy then man would have as limitless a source of energy as the sun itself.

Can man tap this *real* atomic energy? Can he get at the lion's share of the energy locked up in matter or must he always content himself with less than one per cent of this energy?

I have yet to meet a physicist who knows of any way in which this real nuclear energy can be harnessed. Maybe it will be impossible, as is the case with so many things which are important. But man has only just begun his concerted attack upon the nucleus. It is a strong citadel which yields its innermost secrets with the greatest of reluctance but someday it may yield its greatest of all secrets—the key to subnuclear energy. Then man will be truly master over nature. Personally, I think it highly unlikely that I shall live to see this day. But one life span, or what is left of it, is a small time as civilization reckons it.

Whenever I think of the wonders of science and its promise for mankind I think of a remarkable statement by Winston Churchill, whose gift of prophecy is not without honor:

> Man in this moment of his history has emerged in greater supremacy over the forces of nature than has ever been dreamed of before. He has it in his power to solve quite easily the problems of material existence. He has conquered the wild beasts, and he has even conquered the insects and the microbes. There lies before him, if he wishes, a golden age of peace and progress. All is in his hand. He has only to conquer his last and worst enemy—himself. With vision, faith and courage, it may still be within our power to win a crowning victory for all.

H. GAFFRON

Food from Algae

Agricultural experts agree that the world needs radically new sources of food. One lively possibility is the cultivation of edible microörganisms. Food yeasts have already been produced in commercial quantities in several parts of the world from paper-mill and cannery wastes and other plant materials rich in carbohydrate. Most of the product has so far gone to livestock, but it could be used as a supplementary food by man; food yeast is not only edible, but one variety sampled by the editor has a fairly pleasant nutlike flavor. Another possibility is the cultivation of algae, which need no plant materials as their own food, but, like other green plants, only minerals, water, carbon dioxide and sunlight. Here is a readable and lively discussion of algae as a source of food by Dr. Hans Gaffron, a University of Chicago expert. As he himself makes clear, Dr. Gaffron is personally skeptical of the desirability of using algae directly as food for man. He considers population control a preferable means of dealing with the food problem. Perhaps because of this, Dr. Gaffron's article has a realism almost all discussions of algae as food lack. The article is abridged, with Dr. Gaffron's permission, from a paper in the June, 1953, number of the British scientific journal *Research*, a Butterworth Scientific Publication.

During the two hundred years prior to the 1914-18 war, country-wide famines were unknown to the peoples of Western Europe and North America. Despite a rapidly increasing population there had always been an answer to the quest for more food, either by means of improved methods of cultivation at home or by imports from abroad. The fact that, all through

human history, the peoples in the rest of the world have never had enough to eat and that famines succeeded each other in more or less regular waves could be most conveniently ignored since Western man dominated the earth. As the result of two world wars this has changed; famines did occur in Europe and the dominance of the all-powerful European is rapidly waning. In the rivalry among the great powers for the friendship of the so-called underdeveloped countries, a major political weapon is the promise of more food and thus of a higher standard of living for everybody. No wonder that on every side economists are interested in finding out how such promises might possibly be kept and at what price. The weaker nations are interested in the outcome of this search plainly from the point of view of survival.

New Ways to Produce More Food

Until quite recently man had to accept as food what nature was willing to offer in the form of readily edible material among plants and animals. He could improve on this by selecting better strains and growing them faster; that is, in a natural way. A complete break in this development has been initiated by the modern chemist. Given all the tools and the energy he needs, he can certainly produce something edible from the carbon dioxide and the nitrogen in the atmosphere. Since the energy required is, however, always derived at great cost from its ultimate source, sunlight, it is at present still infinitely more practical to study the ways by which the natural conversion of carbon dioxide into organic matter, the photosynthesis of plants, could be made to yield more and better food at lower cost than our age-old system of husbandry.

At least three ways are open to accomplish this. First, there is the elimination of waste; as an example, turning sawdust into edible sugars. Secondly, microörganisms can be used to convert poor food into good food; as an example, growing yeast on molasses, which is comparable to putting cows to pasture. Thirdly, one can attempt to convert every bit of useful light falling on a particular spot on the earth's surface into organic matter; as an example, keeping this area green with plants

during the whole year and harvesting the products of photosynthesis continuously every day of the year.

In the following we shall deal mainly with the third possibility. Agriculture arose quite empirically without any knowledge of the basic process which allows plants to grow. Only modern science has given us the insight to search systematically for an ideal way of utilizing the photosynthetic capacity of green plants. The frightening realization that the problem of how to feed more and more billions of humans on earth is far from solved has very recently led to a series of studies with the purpose of finding out whether certain species of primitive plants called *Chlorella* or *Scenedesmus* or *Euglena* could yield a new type of food for human consumption. These organisms have been cultivated for years in many laboratories for purely scientific reasons. They grow suspended in water to which fertilizers and carbon dioxide have been added. They are mostly unicellular and very small, about the size of yeast cells, and in a dense culture resemble a brilliantly green pea soup. The only achievement in the life of these simplest of plants is to grow in size and to divide into identical daughter cells. Thus they do not produce roots, or flowers, or fruits. For this reason, they are ideally suited for studying the fundamentals of photosynthesis.

It is very unlikely that this green material has ever before appeared as supplementary food on the regular menu of a human tribe. Rarely do these algae occur in nature in quantities which would make it easy to collect a mouthful. Emitting only the faintest of grassy odors, they have been entirely ignored as a crop plant. Yet if we want to believe the prophets and advocates of technological progress, we must look upon these algae and their certainly better bred successors as the ideal food of the future, making it possible to crowd this planet with a few additional (but hardly more intelligent) billions of humans.

Small projects to grow these organisms in sufficiently large quantities to obtain a first impression of their food quality have been started in Germany, Holland, England, Venezuela, the United States, and Japan. The results have been encouraging in so far as it is certain that the organisms can be eaten by

laboratory animals and enterprising men without untoward results. Any indigestibility may be overcome with the aid of the cooks or chemists, and later on by breeding or selecting the right species.

Absolute and Practical Limits of Food Production

In order to see why the growing of algae can be considered, if not preferable, at least more profitable than the raising of ordinary crops, we have to ask what restricts the yield of the latter. The growth of plants on fertile land is naturally curtailed by the following factors: lack of water, low temperature, and lack of carbon dioxide. Lack of what we call fertilizer is mostly man-made by the constant removal of crops; the virgin tropical forests have been luxuriantly green since time immemorial. On the other hand, in the oceans it seems to be lack of fertilizer which restricts the growth of plants; an insufficient concentration of soluble compounds of phosphorus, nitrogen, and sulfur and various micro-nutrients is said to be the main reason why, in general, the seven seas are never as green as the culture flasks in our laboratories (or brown, if we consider diatoms and similar algae). Of all the necessary elements for vigorous plant growth, light is the one which is in abundance nearly everywhere on the earth's surface. Since there is light in excess, the other factors mentioned will determine whether a certain part of the earth's surface will produce a maximum of organic matter per acre per year.

Let us assume that all these earthly requirements for good plant growth have been met, leaving light as the sole limiting factor. Our inquiry about possible improvements in the yield of photosynthetic products then starts with the questions: What are the limits nature has put to all such human endeavors? What is the biggest yield we can ever hope to obtain by converting the light falling on an acre of land (or sea) into combustible and perhaps digestible organic matter?

The calculation is simple. A revision of the result by 100 per cent either up or down (it had better be up) does not alter the meaning of the lesson. . . .

If a frictionless machine were possible, the complete con-

version of daylight into chemical energy expressed here in the form of carbohydrate would give about 500 metric tons of organic matter per acre per year. This is an Utopian limit without any relation to reality. The physical laws of nature enable us to convert all light into heat—actually this happens without any effort on our part—but they do not provide a means of storing energy in chemical compounds without using up some energy in doing work. Most scientists would prefer to believe that the best mankind can hope to achieve is to equal the thirty per cent efficiency of the photochemical mechanism in green cells. This is probably the true limit with which we are allowed to compare the crops of today. It would give us 150 metric tons per acre per year, but in order to harvest them completely we would have to find ways in which to make better use of higher light intensities. The disadvantage of this wonderful mechanism nature has developed is that the excellent efficiency of thirty per cent can be realized only at low light intensities. The plants do their work better on cloudy days. On sunny days they can do more but with lower efficiency, much of the good light being wasted. . . .

We may say, therefore, that an average efficiency of ten per cent will be the practical limit. Converted into food, this means fifty metric tons per acre per year. This yield is within reach of our present efforts. . . . How much room there is for improvement, however, is indicated [by the fact that] we end up with a mere two metric tons per acre per year . . .

The next question is: can we achieve this [improvement] and how?

To keep a certain spot on earth green and fruitful throughout the entire length of the growing season, man has devised artificial irrigation to overcome the lack of water, the greenhouse to counteract low temperatures, and artificial enrichment of the atmosphere with carbon dioxide to compensate for a deficiency in the primary carbon source. Only the first—irrigation (with or without fertilizers)—is practicable over wide open spaces. The use of glass- or plastic-covered areas is certainly limited and can be justified only where a very valuable or rich crop is to be expected. The same holds true in regard to feeding with carbon dioxide. It can be obtained cheaply

only where fires are maintained. Thus these last two, in themselves very effective devices, will almost certainly be practical only in connection with existing industry or if the plants are grown in a way resembling industrial production rather than ordinary farming.

This radical change in methods might be economical if it can be ensured that the specially treated area is maintained as uniformly green as a billiard table. In this case an enormous advantage can be gained compared with ordinary farm land, for the simple reason that farm land is brown, not green, most of the time. At the beginning of the growing season, the germinating crops hardly absorb one per cent of the incident radiation; the rest falls on dead earth. This gradually changes for the better, but even in a field covered with fully grown plants part of the light falls on the earth, on stems, and upon other inactive parts of the plant. A one per cent conversion of the useful light energy into organic matter in the course of the time the plants have been growing is considered a good average. Because of the shorter growing seasons in the temperate zone, the weight of the organic matter thus produced per acre per year is about two tons. A five-, ten- or twenty-fold increase in food production—a harvest of over twenty tons of organic matter per acre per year instead of the usual one or two—is certainly an aim worth striving for. . . . We cannot hope, however, to achieve it with ordinary farm crops. Our first task, therefore, consists in selecting new plants that grow faster, produce a greater percentage of digestible material with a higher nutritional value, and which will keep an area densely covered.

Mass Culture of Algae

It is for this reason that the algae have attracted attention. As pointed out earlier, aquatic plants, such as *Chlorella*, can apparently meet these conditions more easily. A patch of fertilized water may be kept evenly green throughout and since the cells reach maturity in ten to twelve hours, the harvest becomes available within a short time.

The basic recipe is, indeed, quite simple: cover the area two to three inches deep with the right nutrient medium, adjust

the density of the algae so that always somewhat less than one tenth of the incident light intensity reaches the bottom; ensure that the liquid stays saturated with carbon dioxide corresponding to a partial pressure of one per cent of an atmosphere (thirty times the concentration in ordinary air), stir vigorously and maintain at a temperature of 27 degrees C. If this is done, and a spot selected where throughout the year the average daylight is about one tenth the intensity of full sunlight, a harvest up to fifty tons of dry organic matter per acre per year can be expected.

We arrive at this figure by simple multiplication. Our laboratory experience shows that 15 mg. of algae below a surface of 1 cm^2 absorb over 80 per cent of the energy of white light (incandescent lamp). Under the above conditions, the algae divide in the course of ten hours. We must, therefore, cover one acre. . . . 606 kg. of algae. Since the algae should dutifully double their weight in the course of one day, we can harvest 606 kg. per day, 220 metric tons of live algae per year or the equivalent of fifty tons of dry organic matter. . . .

Comparison With Field Experiments

How does this compare with the yield obtained by operating a true model installation outdoors? Professor H. Tamiya's pilot plant in Japan for mass culture of algae yielded during the month of August, 1951, a crop which, extended over the year, would mean thirty tons of dry weight per acre per year. The method used in Japan was to let the suspension flow and circulate through open concrete ditches, periodically recharging it with carbon dioxide in a tower where air enriched with carbon dioxide was bubbled through the liquid.

Professor Tamiya's result shows two things: first, that simple extrapolations from laboratory experiments yield a not unreasonable estimate of what can be expected under optimal conditions even on a large scale; secondly, that Professor Tamiya's first attempt succeeded amazingly well. The trouble is that the temperature does not stay at 25 degrees C all the time in Tokyo. During winter, at temperatures around 4 degrees, the yield was very low and the fluctuation of temperature during

the year reduced the actual annual yield to ten tons per acre. In Boston, A. D. Little and Company in an experiment on behalf of the Carnegie Institution arrived at a figure of fifteen tons. The system used there was a closed one. The algal suspension was pumped through four-foot wide, plastic, flexible, transparent tubes laid out on the roof of a building. Cooling was one of the major problems. Conditions in Texas allowed Professor Jack Myers to make an estimate of over eighteen tons per year.

Producing Food on the Rooftop

Before comparing these figures with those of other agricultural crops, let us make an excursion into some not-so-utopian future. If fifty per cent of the material were digestible and half of this again consisted of proteins, two kilograms per day would be more than enough to keep a man in good health. If we aim to produce nothing more than a source of protein this amount would easily serve five to six people. Assuming that we have learned by then how to produce not thirty but fifty tons per acre per year, the two kilograms per day could be harvested from an area not larger than 62 x 100 feet. In other words, the algae cultured on the flat roof of a somewhat extended ranch house could provide all the protein and some of the carbohydrate for the family living below it (assuming they lived in a climate without severe, dark winters).

This house should have a roof slightly inclined to the south. A steady stream about two inches thick of a deep-green algal suspension would be pumped over the roof. The carbon dioxide needed to charge the suspension might be derived from the burning of garbage and of refuse usually drained into the sewers. In this case, the latter would be first dried in the sun. Part of the drainage from the house could simply be sterilized and added as such to the suspension. Thus most of the inorganic salts and some "growth factors" would be recirculated. The materials used by the plants, and water and carbon dioxide lost into the air, are the only replacements required. In other words, the thriftiness of the Chinese in fertilizing their own gardens could be copied with the aid of modern scientific knowl-

edge. Since the water layer on the roof absorbs also all the heat radiation, the house below is practically insulated against the heat of a summer's day. On the other hand, we cannot allow the suspension to become warmer than 30 degrees C or, if thermophilic strains have been bred, let us say, up to 40 degrees C. In other words, there is a problem of cooling. This can be taken care of by circulating the suspension in such a way that it exchanges its heat with a chemical system where the heat is utilized to melt crystals of suitable chemicals. In this way the heat energy can be stored. The process would be reversed and both the algal suspension and the house would be kept at temperatures above 15 degrees C on cold days. Such solar heating systems have already been successfully installed in model homes near Boston. . . .

All this is not as utopian as it might sound. Any rich man willing to experiment could have a house like this built for perhaps five times the usual cost. . . .

If ever a small factory similar to this outline were to be set up in earnest, it is unlikely that the harvested algae would all be consumed on the spot. We encounter the additional problem—which the algal project shares with the food industry in general—namely, how to preserve the fresh product. Sun drying is obviously the cheapest way, but not the best.

Having found an answer to the question of how much our daily light may provide for us and having shown that the yields thus calculated are within reach of present technical developments, provided we abandon farming and turn to mass culture of algae, we come to the third question which, in its way, is equally fundamental. Who is willing to eat this material? And if it is found to be acceptable as a diet, will it easily compete economically with other crops? . . .

Feeding experiments in Dr. M. J. Geoghegan's laboratory have shown that rats can thrive on a mixed diet with algae as their sole protein source. If by a simple treatment most of this protein and part of the carbohydrates and fats of the cell could be made digestible to man, the enthusiastic promotion of algae as food by scientists like Dr. R. L. Meier, who is interested in economic planning, would seem justified. Dr. Meier called our attention to the courageous attempts of Dr. Jorge Jorgenson,

Venezuela, to improve the nutritional value of food available for leper patients at Cabo Blanco. Crude, mixed cultures of algae were grown in open bowls standing in the sun. After testing the food value of the algae on mice, algal soups were given to humans. "Severe cases of malnutrition were found to be greatly aided by these algal soups." . . .

According to Professor Tamiya a pound of dry soya beans costs the equivalent of 6 to 7 U.S. cents in Japan, and he is confident that the price for algae could be brought down to the same level. The advantage of *Chlorella* is most obvious in connection with the saving in space since the best soya bean crops need about ten to twenty times more acreage. The production of algae in the United States, according to the latest estimates of A. D. Little and Company, would allow a price as low as 25 cents per pound dry weight. If it could be lowered to 15 cents, the proposition would appear "interesting." . . .

No matter at what low level the running expenses could be kept, the greatest handicap from a purely economic point of view is the high initial capital investment. The so-called hydroponic installations to grow tomatoes and other suitable vegetables in containers filled with nutrient medium require $4,000-$8,000 per acre, and such a layout is relatively simple compared with the requirements of our continuously circulating *Chlorella* suspensions. Meier anticipates that with concrete surfaces and settling tanks a cost of $20,000 per acre could be anticipated. Utilizing plastics to provide a water-impenetrable layer at the bottom and perhaps also the cover, the investment per acre would run up to $9,000. This figure is taken from one of Meier's tables using as a basic assumption a farm of the size of a thousand acres. There is no doubt that in the beginning no one will venture to start on such a large scale, and of necessity the investment per acre will be above $10,000 if the new enterprise comprises only a few acres. This should be compared with the cost of reclamation of the polders in Holland where $700 per acre was considered a high investment. . . .

Conclusions

We have the paradoxical situation that those countries which can afford to start with investments of such magnitude have little or no reason to change their food habits. The one exception is Japan where the need for food is pressing, labor is cheap, and at the same time industrial skill is highly developed. In Japan, too, the acceptance of algae as food will not encounter great resistance since the population is accustomed to eating some of the larger algae taken from the ocean. . . .

It is, of course, impossible to predict how soon the countries of Western Europe will become either so poor or so overcrowded that dairy products will no longer be available. In this event, the groundwork has been done with which to produce a reasonable substitute. As things stand at the moment, it appears that the so-called underdeveloped areas and the ancient countries of the East, where the food problem is acute, are not yet ready to start on their own initiative with an industrialized food production in the manner outlined above, particularly in view of the fact that the older means of improving crops have not been exhausted.

What, then, should be done? It is a fascinating and perhaps urgent problem to find out how to convert our daily supply of solar energy into chemical energy, useful in many ways, for many purposes. Since at present only the plants can do this efficiently, studies of the growth and photosynthesis of algae should be encouraged. It is one thing, however, to promote this type of research because it is fundamentally important, and another to believe that success along this line will solve the terrifying population problem.

Pessimists are everywhere disliked no matter how well-established the facts are on which they base their dour predictions; their warnings as to the increasing urgency of the problem posed by the faster and faster exploitation of natural resources and an ever-increasing human population are either ignored or seemingly refuted by pointing to the progress reports of the specialists. . . . In the case of our algae, what the specialist can readily predict is merely that mass cultures of these organisms will be introduced wherever an acceptable product can be sold

at a profit and that this will not happen in many countries during the next twenty years. During these twenty years the population of the United States alone will have increased by over forty million, and on the earth as a whole—if no hydrogen bomb interferes—by more than half a billion. Despite some technical progress, the enormous problem of adequate food for all will very likely have become more pressing than ever. . . . It is time to acknowledge publicly (and not shyly in one half sentence of the specialist's summary) that it is not possible to solve the population problem by way of an ever-increasing food production alone. We must have populations in balance with the area from which they can be easily fed. The reporter of the future will certainly hail it as a great achievement when our crowded great-grandchildren shall subsist contentedly—because they know no better—on hydrolyzed sawdust and predigested, vitaminized algae. But we, should we not rather strive to preserve for them conditions where they may still be able to find a garden in which to pick fruit from a live tree?

LEONARD ENGEL

Little Gadget with a Large Future

Previous articles in this anthology have reported on a few of the accomplishments of the vacuum tube, the ubiquitous gadget that brought the electronic age and that has been described as the most revolutionary invention of the past century. Here is a report on the transistor, the tiny device that promises to take the place of the vacuum tube (in most uses) and to carry the electronic age farther than anyone now dares dream. The article is reprinted from *Harper's Magazine* for March, 1952. Illustrations are reprinted by permission of Sigman-Ward.

In July, 1948, the *Physical Review*, the almanac of physics, published three short papers from the Bell Telephone Laboratories. The first, by John Bardeen and Walter H. Brattain, began: "A three-element electronic device which utilizes a newly-discovered principle involving a semi-conductor as the basic element is described." Thus was announced, in deceptively restrained language, an invention which may change our way of living more than atomic energy. The invention is the transistor, a device which performs about the same functions as a vacuum tube but is so much more convenient that it is destined to superimpose a new technological revolution on the already very revolutionary branch of technology called electronics.

To begin with, the transistor is much smaller than the vacuum tube. One model is about half the size of a pea and smaller ones still can easily be made if they are wanted. Further, there is no vacuum and no glass envelope, no filament to burn out.

Junction transistor (above) is much smaller than even today's small vacuum tube (left).

Hence transistors should last almost indefinitely; transistors probably capable of operating continuously for more than 100,000 hours (over eleven years) have already been made in the laboratory. Finally, the transistor consumes vanishingly small amounts of power and generates almost no heat. These two properties alone make the transistor invaluable, for it appears that two of the principal obstacles to new electronic wonders have been the large amount of power required and the heat given off by the vacuum tube.

Dr. Louis Ridenour, dean of the University of Illinois Graduate College, predicts that the transistor will make possible computing machines with a hundred times as many computing elements as any calculator now in existence and, for problems within their grasp, a tenth as competent as the human brain. The transistor may also bring into being the elaborate electronic control systems which, we have been told, are ready to take over many of the intricate but tedious tasks of an industrial society, but which never got off the ground in the vacuum-tube era: the all-electronic record-keepers, the robot inventory and warehouse control systems, automatic centralized control for air and rail traffic, automatic utility meter reading and billing, and so on. This super-compact, durable successor to the vacuum tube likewise has obvious applications to military electronics. On a homelier plane, the transistor promises telephones with built-in amplifiers, matchbook-size hearing aids capable of running for several years on a single set of batteries, really small portable radios, TV sets whose "tubes" will never need renewal (except for the picture tube, which is a relative of the X-ray tube and not a conventional vacuum tube at all, and therefore won't be replaced by the transistor). And, of course, the transistor will bring contrivances and gadgets that cannot now be imagined.

II

The device that is to accomplish all this is a sort of educated cousin of the old crystal detector, which Father used in the headphone radio set he built when he was a boy. Like the crystal detector, the transistor makes use of the special electrical prop-

erties of a curious class of materials called semi-conductors, of which we'll be hearing a good deal more in the next ten years. To say more about the transistor, though, it is necessary to go back briefly over the marvelous, turbulent history of the electronic devices that have given us not only Eniac, the 18,000-tube calculating machine, but also Kukla, Fran, and Ollie.

The story begins on a day in 1883, when an adventurous glass blower in Thomas Edison's laboratory sealed a metal electrode into the head of one of Edison's new incandescent lamps, the first electric light bulbs. Edison did not understand, and saw no use for, the odd thing that happened when the electrode was connected to the positive terminal of the battery and the lamp turned on. The "Edison effect" led, however, some two decades later, to the vacuum tube and the real birth of radio.

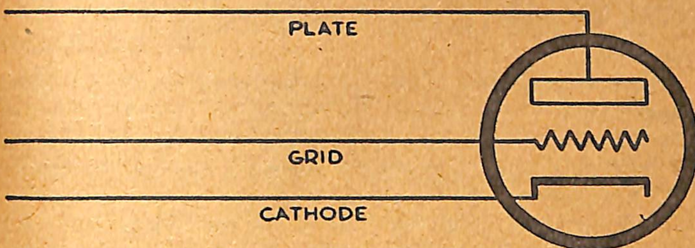
When the electrode of the doctored lamp was connected to the positive terminal of a battery and the lamp switched on, a current could be detected in the wire from the electrode to the battery. There was no current in the wire, on the other hand, when the electrode was connected to the negative terminal of the battery. In other words, a current could flow through the vacuum inside the lamp, but only in one direction—from filament to plate, as it turned out. What was happening was that electrons were being boiled out of the hot glowing filament; since electrons are negative in charge, they were attracted to the electrode and moved toward it as long as the electrode was positively charged.

In 1905, a British physicist by the name of J. Ambrose Fleming built a tube based on the Edison effect. It contained two elements: a filament hot enough to boil off electrons and an electrode or, in modern radio parlance, plate. The "Fleming valve" could be (and, in most home radios, still is) used to "detect" radio signals, that is, convert the signal picked up by the antenna into a form suitable for moving the diaphragm of earphones or, after amplification, a loudspeaker.

The crucial step was taken the next year by a youthful American engineer, Lee de Forest. De Forest discovered that the current flowing from filament to plate could be controlled by a much smaller current in a fine wire grid placed between the

filament and the plate. All the variations in the smaller current were impressed upon the larger, making the latter a faithful, but much enlarged, replica of the former.

This was the three-element vacuum tube, or audion, as De Forest called it. The audion was soon at work amplifying long-distance phone calls. Nothing much else was done with it for several years, however, until the invention of the regenerative circuit (the first practical radio circuit) by a Columbia undergraduate, Edwin H. Armstrong, who was later to invent FM.



The principle of the vacuum tube is still essentially the same as in de Forest's audion. The flow of electrons from cathode (filament) to electrode (plate) is controlled by a much smaller current in the mesh of fine wire grid.

The vacuum tube has since proved to be one of the most fruitful inventions in history, the source not only of an astonishing array of other inventions, but of some of the most torrid patent battles on record. One was the battle between Arnold of A T & T and Langmuir of General Electric over high vacuum, which greatly improved the vacuum tube. Another, the celebrated struggle between Armstrong and De Forest over the regenerative circuit, led to the longest, bloodiest patent suit in United States court annals.

Since De Forest's day, the vacuum tube has undergone innumerable changes and permutations. There are now tubes with four, five, six, and even seven or eight elements, to attain vari-

ous refinements of control or suit them for special purposes. There are tubes half an inch long (for hearing aids) and tubes bigger than a man. In 1950, American plants produced over 400 million vacuum tubes in close to a thousand varieties. The principle, though, is essentially the same as in the original De Forest audion.

Let us see a few of the useful things that can be done with this ingenious device for patterning a large current after a small one—things that, as we shall see, can be done even more efficiently by the transistor. The most obvious is to amplify weak currents, such as those generated by a radio signal or by the modern high-fidelity phonograph pick-up. Amplification is the purpose for which the largest number of vacuum tubes is in fact made.

Another application is crucial to the radio sending station. Radio signals are generated by oscillating electric currents. Electric currents can be made to oscillate in a number of ways, but some means of reinforcement is always needed to keep the oscillations going. A suitable means is a special type of vacuum tube known as an oscillator. Part of the oscillating current is fed back through the oscillator, where it is continuously amplified and regenerated, keeping the radio signal strong and clear.

Vacuum tubes can also be used as relays to turn electrical equipment on and off, for if one current can be made to follow the pattern of another, it can be turned on and off by the latter. Thus vacuum tubes can be made to open doors, ring burglar alarms, and so on. Further, they can be made to count the pulses of electricity generated by radioactivity, as in radiation detectors, or by "programing units" in computing machines.

III

Two generations of scientists and engineers have elaborated these simple capabilities of the vacuum tube into an imposing assortment of devices. Amplifying tubes are at the heart of not only radio and TV, but sound movies, dictation machines, wire recorders, radio facsimile, and long-distance telephone. Vacuum tube amplifiers, oscillators, relays, pulse generators, and pulse counters are the stuff of guided-missile controls, radar, prox-

imity fuses, electronic gun- and bombsights, and military communications. We would possibly be better off without the latter, but essentially similar tubes are required for air and marine navigation, and also perform hundreds of other jobs which contribute substantially to our well-being, from curing rubber and plastics by high-frequency induction heating to checking the labels of drug bottles. Last but not least, vacuum tubes are the sensitive eyes and ears of science, and can do much of its routine brainwork. The electron microscope makes visible the infinitesimally small; action-potential apparatus tunes in nerve impulses; electronic controls regulate atom-smashers; electronic computers whip through the unbelievably tedious mathematical equations which seem to arise from even the simplest research problems.

But paradoxically, the vacuum tube, which made radio and electronics possible, has become an obstacle to further progress. There are two chief difficulties. The first is that the vacuum tube is inherently short-lived and unreliable. The second is that the vacuum tube, in Dr. Ridenour's phrase, is the grandchild of the electric light bulb. It was originally conceived as a hot wire inside a bottle and, like its progenitor, it requires a large amount of power to operate and thus dissipates a great deal of heat.

The vacuum tube is a self-consuming device. As in the ordinary light bulb, the heated filament (or heating element in tubes that employ indirect heating) is bound to fail sooner or later. Of course, the filament can be made heavier, but then a larger current will be needed to boil off electrons. The problem is compounded by price competition in the tube industry. Manufacturers have performed prodigies of ingenuity in the fabrication of vacuum tubes, but the primary object has been to cut costs for the mass radio and television market. Vacuum tubes, consequently, are not as carefully made or as dependable as they might be; most have a useful life of only a few thousand hours.

This is not a serious matter in an inexpensive six-tube radio set. It is quite inconvenient, however, in a TV set with twenty-five to thirty-five tubes, where the chance of set failure as a result of tube failure is multiplied by five, and where an expen-

sive service man is needed to determine which tube failed. It is a still more serious matter in long-distance telephones and in complex devices like electronic calculators. The completion of a telephone call between New York and San Francisco, for instance, depends on the proper functioning of nearly a quarter of a million electrical components, including about 1,200 vacuum tubes in repeaters or amplifiers spaced roughly every eight miles across the continent. The IBM Selective Sequence Electronic Calculator, one of the simplest high-capacity general-purpose computers, has no less than 12,500 vacuum tubes, of which 125 burn out every month; elaborate daily tests and other expensive precautions are necessary to prevent tube failures from causing the machine to spew forth a nightmarish deluge of wrong answers.

By the exercise of special care in manufacture, much can be done to prolong the life of a tube beyond ordinary limits. As an illustration, there are six repeaters, each containing three vacuum tubes, sealed into the new Havana-Key West submarine telephone cable. The Bell system engineers who laid the cable are confident that the eighteen tubes, which are inaccessible for replacement, will serve for at least twenty years. But nearly as many years were needed to design, manufacture and test the eighteen tubes. And the telephone company, which probably builds the most durable vacuum tubes in the world, has never been able to manufacture at practicable cost tubes sufficiently dependable for two important purposes—dial switching and amplification on local lines.

The second difficulty inherent in the vacuum tube, the large amount of heat it dissipates, imposes severe restrictions on the design of electronic equipment, particularly in respect to size. As electronic equipment grows in complexity, it grows in bulk. Designers have attempted to meet this problem by "miniaturization." Vacuum tubes and other circuit components have been produced in miniature and subminiature versions. Conventional wiring has been replaced by "printed circuits" and other forms of minute, prefabricated wiring. The "air has been designed out" of equipment; components fill every nook and cranny of the set.

Yet there are limits beyond which the miniaturization of

vacuum-tube equipment cannot be pushed. Aside from the difficulty of fabricating and assembling very small components, there is the circumstance that miniature tubes of comparable performance have the same power requirements as standard tubes and therefore dissipate just as much heat. The National Bureau of Standards, for example, recently worked out a miniature edition of the standard aircraft radio range receiver. The miniaturized set has less than one-fifth the bulk of the standard receiver. Both, however, consume roughly the same amount of power, some thirty watts. In the miniature range receiver, this results in the dissipation of heat energy at a rate equivalent to a tenth of a watt per cubic inch—just about the rate of energy released in a kitchen oven. The temperature inside the miniature range receiver accordingly may reach four hundred degrees Fahrenheit.

If the temperature were to go higher, it would soften the glass in the tube envelopes. As it is, high-melting-point solders must be used for connections, greatly increasing the tediousness and cost of assembling miniaturized equipment. More serious, the excessive heat shortens the life not only of tubes, but of other components of the set, adding materially to the chances of set failure.

IV

The difficulties that have made the vacuum tube a troublesome, if remarkably versatile, tool of technology are neatly avoided by the transistor. Like the vacuum tube, the transistor (so named because it transfers an electric current across a resistance) imposes the pattern of one current on another; thus it can also be employed to amplify a current or generate a radio signal, or as a relay. In the new device, however, electrons are not boiled out of a filament; the current flows through a crystalline solid.

This indeed sounds something like the crystal detector of radio's early days. The transistor, in fact, grew out of a rebirth of the crystal detector. During the war, it was found that the two-element vacuum tube detector used in standard radio wouldn't do for radar. The crystal detector proved much more

effective and therefore stimulated a renewed study of semi-conductors, the curious materials of which crystal detectors are made.

Semi-conductors are substances falling somewhere between conductors and insulators in their ability to conduct an electric current. They do not conduct it as easily as a metal like copper; but they do not have the electrical resistance of an insulator like porcelain or glass. One semi-conductor is galena (lead sulfide), the crystalline mineral originally used in crystal detectors; another is the substance now used, germanium, a fairly common semi-metallic element obtained as a by-product of zinc refining; still another is silicon, one of the principal constituents of sand.

Semi-conductors have many extraordinary properties. Thus some release electrons (i.e., generate a current) when struck by light; others have the opposite property, giving off light when bombarded by a stream of electrons. The former property is the basis of the "electric eye," the latter of the TV picture tube. Other semi-conductors can be used to transform heat energy directly into electricity; scientists at the Massachusetts Institute of Technology are currently looking into an ingenious scheme for using them to generate electricity from solar (and later, perhaps, atomic) heat without boilers or dynamos.

To return to the transistor, systematic study of semi-conductors was undertaken soon after the war by, among others, a group of physicists at the Bell Telephone Laboratories under William Shockley. Bell Labs originally had no specific "practical" purpose in mind; the object at first was simply to learn something about the inner mechanics of semi-conductors. As had happened with the Edison effect, however, an essay in "pure" research paid off with an unexpected discovery of whopping commercial importance.

The Bell group found that semi-conductors are indeed curious materials. Although crystalline, they often do not have the right number of atomic electrons for a normal crystal structure. There may be either too many or too few. If there are too many, the excess electrons can travel through the crystal much as through a vacuum. If there are too few, on the other hand, the "holes," or vacant electron positions, can also travel

through the crystal as the insufficient number of electrons dance about in a futile attempt to fill the vacancies. Most remarkable of all, the flow of electrons and holes can be controlled by a current applied at barriers between electron-rich and electron-deficient regions, in much the same way as the flow of electrons through a vacuum tube is controlled by the current in the grid.

Of the two key men in the group that worked out this picture of what happens in semi-conductors, one had just turned forty: John Bardeen had come to the Bell Laboratories from the University of Minnesota and the Naval Ordnance Laboratory after the war. Walter H. Brattain, a few years his senior, had spent most of his professional career as a Bell Labs physicist, studying the flow of electrons. Dr. Bardeen, in particular, is credited with important contributions to the underlying theory, which not only threw new light on semi-conductors but led Drs. Bardeen and Brattain to concoct a revolutionary device for exploiting them, the point-contact transistor. The latter, the first tool of the new era in electronics, is a little larger than the eraser on the end of a lead pencil. It contains, inside a simple cylindrical metal case, two hair-thin wires—"cat's whiskers," in radioman's language—resting on a small piece of germanium soldered to a metal disk. When properly connected, a signal put into one cat's whisker comes out through the other amplified one hundred times.

An even simpler type, the junction transistor, was developed by Dr. Shockley last year. The junction transistor is a germanium rod perhaps a tenth of an inch long in a plastic case half as large as a pea. Exceedingly minute impurities have been introduced to make the ends of the rod electron-rich and the center deficient in electrons; the electron-rich ends serve as "filament" and "plate," the electron-deficient center is the "grid." A wire from each section of the rod completes the transistor assembly.

V

Beside simplicity and small size, the great advantage of the transistor is the fact that the electrons and holes are lying about loose inside the crystal, ready to go to work. No energy is needed to boil them out of a filament. As a result—to men-

tion only one convenient feature of transistor devices—there is no delay for warming up. Transistor equipment comes to full strength the instant it is switched on; long-distance telephone amplifiers, ships' radios, and other devices which must be ready to operate on demand will not need to be kept turned on continuously.

There is, of course, no filament or heating element in the transistor to burn out. Consequently, transistors should last almost indefinitely, subject only to the limitations of abuse, deterioration through diffusion of water vapor through the casing, and so on. Transistors have not been in existence long enough for the life span to be known with certainty, but development engineer J. A. Morton estimates from survival curves that the first point-contact transistors will have lifetimes of about 70,000 hours and junction transistors, about 100,000 hours. This is already long enough to outlast most home radios, making it possible to dispense with sockets and expensive demountable wiring in home receivers. It should not be very difficult to make transistors good for half a century of continuous service.

The most striking feature of the transistor is the modesty of its power requirements. In the vacuum tube, by far the greater part of the power goes to heat the filament; only a small part reappears as output signal. In devices like vacuum tube relays and in the first stages of a radio receiver, there is usually no need for an output signal of more than a few millionths of a watt; only in the sending station oscillator and in the part of the radio receiver that drives the loudspeaker are more powerful outputs necessary. Yet, to put out a millionth of a watt signal, the average vacuum tube requires the expenditure of one or two watts of power; the most economical hearing-aid tubes, which sacrifice performance in favor of low power consumption, require thirty thousandths of a watt. This is, remarks Ralph Bown of the Bell Laboratories, about like sending a twelve-car freight train, locomotive and all, for a pound of butter.

Since it needs no energy to set electrons free, the transistor requires only the power necessary for the desired signal. A millionth-of-a-watt signal is put out with a total expenditure

of power of very little more than a millionth of a watt. Bell Labs has a demonstration junction transistor circuit which can operate on the energy picked up by a photoelectric cell held in front of a white shirt, about six ten-millionths of a watt—the energy expended, a Bell lecturer has calculated, by a flea jumping once every eight seconds. As the amount of energy wasted on heat will be negligible even in powerful transistor circuits, transistors may be packed as closely as we please in miniaturized equipment, without any danger whatever of overheating.

The transistor is not ready for immediate assumption of the vacuum tube's many roles. Its new properties call for new circuit arrangements, which will take at least a little time to work out; present-day radio represents not only four decades of tube design but four decades of circuit-making. The most powerful transistors made thus far, furthermore, have a signal output of only two watts, roughly a fifth of the power needed to operate a loudspeaker. Also, the junction transistor, which has the most desirable characteristics in other respects, cannot in its present form handle shortwave, FM, or television frequencies, and hence can be used only for special purposes in such equipment.

Nevertheless, the new era in electronics is at hand, for equipment based on the revolutionary Bell device will soon be in production. A key part of the new long-distance dial telephone system will be an automatic route selector based on a phototransistor, a combination of photoelectric cell and transistor, for "reading" and "translating" coded intercity telephone route cards. General Electric, RCA, Sylvania, and other major electronics companies, moreover, have active transistor research and development programs. GE is near production of a device closely related to the transistor, the n-p diode, which promises to be the simplest and most efficient means yet devised for converting alternating to direct current. One model, about the size of a large olive, can put out enough direct current for a row of aluminum refining pots or electroplating baths; a handful of them can replace an entire roomful of rectifiers. Were it not for defense delays, another type of n-p diode would have gone into GE's 1952 television sets instead of the rather inefficient selenium rectifiers now used in most home radio receivers for converting the house AC supply into the DC needed by the

set. If transistors had been available, a GE engineer adds, they could also have been used in 1952 TV sets in place of four or five of the thirty or so tubes.

This is certainly but a small and altogether insignificant sample, however, of what is to come. Qualified electronics engineers are agreed that the transitor is certain, before not too many years, to replace the vacuum tube in nearly all its present applications. The result will be an explosively rapid series of developments in two directions. Radios, television receivers, hearing aids, and the like will become simpler, more efficient, more reliable, and (within limits set by picture tubes and loudspeakers, which are necessarily large) smaller. The inherent simplicity and convenience of the transistor will also be exploited to construct devices much more complex than can now be attempted, and therefore much more competent, more versatile, and more useful. All sorts of tasks which must now be performed by hand (or at best with partial aid from machines) will fall into the province of electronics. Beyond this, the transistor will doubtless lead to instruments and machines that cannot presently be imagined. The quietly announced invention of Drs. Bardeen and Brattain opens up new horizons as wide as those opened up by the De Forest audion fifty years ago.

E. W. LEAVER and J. J. BROWN

Machines Without Men

The last few years have seen a rash of technical and popular articles on a portentous development that may have as great effects on life in the remaining decades of the twentieth century as the Industrial Revolution had on life in the nineteenth. The development is "automation," the application of automatic controls to manufacturing and to an ever-increasing variety of other tasks, from keeping inventory to the recording of phone calls and preparation of phone bills. Many of the ideas now being discussed go back to an article that appeared in *Fortune Magazine* a decade ago (issue of November, 1946). The article was "Machines Without Men"; its far-sighted authors were two Canadians, E. W. Leaver, an electronics engineer, and Dr. J. J. Brown. "Machines Without Men" is reprinted here in condensed form by special permission of the editors of *Fortune*.

Imagine, if you will, a factory as clean, spacious, and continuously operating as a hydroelectric plant. The production floor is barren of men. Only a few engineers, technicians, and operators walk about on a balcony above, before a great wall of master control panels, inserting and checking records, watching and adjusting batteries of control instruments. All else is automatic. Raw materials flow in by conveyor, move through automatic inspection units, fabricating machines, subassembly and assembly lines, all controlled from the master panels, and arrive at the automatic packaging machines as finished products —radios, refrigerators, tractors, fountain pens, carburetors, helicopters, or what you will.

This factory of tomorrow will be as different from the present manufacturing establishment as a hydroelectric plant is

different from an old steam-power installation fed by a line of boiler-tenders and men digging coal. Once a hydroelectric unit is installed, all that remains is to control and distribute the power. The same, in principle, will be true of the factory of the future. Our present machine tools belong to the former coal-and-iron technology. The new organization of machines will be electrical. This is made possible by the development of a great variety of circuits and devices for linking machine units together in a new way. It will entail a greater and greater regimentation of machines, rather than of men.

Nowhere is modern man more obsolete than on the factory production floor. Modern machines are far more accurate and untiring than men. Available and in use are hundreds of electronic gadgets that can do everything a workman can, and do it faster, better, and continuously. But such gadgets heretofore have been merely attached as accessories to the familiar types of production machines. . . .

The fully automatic factory requires three types of machine units, all now available in reasonably efficient form. These basic units fall into three classes: (1) to give and receive information, (2) to control through collation, and (3) to operate on materials. Each class must first be considered in its separate parts before attempting to put together a full-scale production unit.

The machine units dealing with information correspond in function to the human senses—sight, hearing, smell, taste, and touch—as well as the more involved processes of memory and cogitation. These exist in dozens of electric and electronic forms, and may be divided into four main types.

First, there are the detectors whose function is to *obtain* information. Examples are devices for detecting differences in pressure, such as microphones and vibration pickups; for detecting differences in temperature, such as thermocouples, thermometers, pyrometers; and for "seeing," such as photoelectric cells. Equipment of this kind is now widely used as supplementary control and warning devices in industry. The second type of information unit *carries* information from one place to another. Example: the telephone circuit. The third type, corresponding to human memory, *records* information and stores

it for repeated use. Common examples are the office Dictaphone, all manner of punch-card systems, perforated tape, and recordings on plastic, paper, wire, and film. The last type of information unit is one that *calculates*. Examples range from the adding machine and other business machines to the new electronic-tube counter known as ENIAC.

The second class of basic machine unit, the collation-and-control device, is a chassis of electronic tubes and circuits that accepts information fed into it by information units and in turn feeds controlled power to the operations units in accordance with this information. Basically this class of machine compares electrical impulses from different sources and, if they do not agree, applies the difference to other circuits that act to equalize the impulses. It also is capable of accurately controlling large amounts of power to drive production machines. Such equipment, using bridge circuits and thyratron tubes, is already widely used in industry in individual machine controls. In its new application it is the link between the informational class of machine units and the machines that actually make things.

The third class of machine unit is that which performs an actual manufacturing operation. These operations may be subdivided into three types.

The first is *transport*, i.e., all sorts of moving and carrying, whether by pushing, rotary, or reciprocating motion. The material moved may be solid, liquid, or gaseous. The second fundamental operation is *fabrication*. It includes all the operations on a mass of raw material from the time it enters the plant to the time it leaves—from such operations as rolling, cutting, punching, forming, assembling, polishing, and painting to the final operation of packaging. The third type of operation is *holding*. In some machines the work is held while the cutting tool moves (shaper, mill, drill, forge, saw); in some the tool is held firmly and the work is moved (lathe, router); while in others both work and tool move (surface grinder, thread-cutting lathe, tool-post grinder, thread grinder). In each instance the holding is as important as the cutting.

Automatic holding and guiding mechanisms are foreshadowed in many parts of modern production machinery. An automatic screw machine makes use of fingers to feed materials, an

automatic collet to grasp and hold them, and moving arms to carry a cutoff tool from one point to another. The gain in automatism here, however, is at the expense of flexibility. To obtain both flexibility and automatic production requires a new approach to machine design. One result of this new concept we call a hand-arm machine, combining most of the present automatic holding devices and some new ones.

Hand-arm machines may take many possible forms, some designed for work of extreme finesse, others for heavy duty. Basically they will consist of an articulated arm, mounted in a turntable device on a heavy base, with the free end equipped with a holding fixture—gripping fingers, vise, magnet, or collet, depending on the nature of the operation—in place of a hand. In the base are the mechanism and circuits to rotate the turntable, pivot and flex the arm, and move the holding fixture. This machine is capable of all the motions of a workman's arm, but in addition the position of the extremity can be very accurately controlled, and the hand itself rotated at the wrist. It already exists in prototype.

With these three classes of machine units clearly laid out, we are now in a position to assemble the elements of a representative machine tool. A simple part might require only one or two units of each class; one requiring many operations would need perhaps a score of each. What we are about to describe is a production machine for making a single part, not a complete product. The part, we shall suppose, is a brass ring with internal thread to hold the microphone in a telephone handset.

Engineers first lay out the blueprint and operations for the part to be manufactured. The blueprint specifications and sequence of operations are then recorded, say, on a perforated paper roll, like an endless player-piano roll, with the perforations corresponding to the type and length of operations the machine tool must perform to make raw brass tubing into the brass ring. This record is loaded into a type of informational unit called a master record-control rack, where it moves under a pickup head at constant speed. The pickup translates the perforations into electrical impulses, which are transmitted to the production floor and fed to a collation-and-control unit. As the collation unit receives the starting signal, it sends controlled

power to start the hand-arm and fabricating machines.

The central fabricating unit for this type of operation might be an automatic lathe with standard spindle to hold and rotate the material, a compound rest to hold the threading tool and direct it in making the cut, and two hand-arm machines to handle material, change tools, and perform the final milling operation and cutoff. Brass tubing feeds in automatically through the headstock. The power fed to the machines is determined by the control impulses sent down from the master record, and its duration is controlled by the length of perforations in the record roll. The timing of the machine operations is determined by the position of the perforations relative to one another. The record moving through the rack causes everything to take place in orderly procession. During fabrication, tools may change in the holding fixture, the position of the work in the holding unit may change, and speeds of rotation and feed will change.

As soon as any hand-arm or fabricating machine moves, detector devices go into action. These are an integral part of the unit, mounted to "watch" every critical operation. One such device might be a detector to pick up excessive vibration in the lathe spindle. It consists of a detector head clamped to the lathe and connected by a circuit to a basic information unit on the floor beside it—an electronic chassis composed of a standard power pack, amplifier, and distributor panel plugged into one another to form a single unit. The pressure head detects changes in pressure (vibration) at the spindle and converts them to electrical impulses. The amplifier increases their power and feeds them at standard impedances and power levels to the distribution panel, which sends them to the collation-and-control unit. At the slightest increase in vibration, the collation unit adjusts the power to the lathe spindle. One or more detector devices may be connected through the information unit to the collation unit, which constantly compares their impulses with the standard impulses coming from the master record and accurately regulates the whole operation.

At the end of the cycle the finished brass ring is dropped on an outgoing conveyor belt, where it passes an informational unit equipped with detectors to inspect its shape and dimen-

sions. The detectors are connected with the collation unit, which compares with the master record and passes or rejects the part. Then the record roll, being an endless tape, starts the cycle of operations all over again.

Within each class, the basic machine units take many different forms. The informational unit, for instance, may be merely a remote indicating thermometer sending out electrical impulses as temperature rises, or it may be the complicated master record-control rack translating perforations into electrical impulses to control all the machines. Another simple information device might be a photoelectric detector watching the cherry-red condition of a hot tungsten carbide cutting tool. If a record of operations is desired, detector impulses may be fed to a simple counter, to an indicator panel with plug-in meters or oscilloscope for visual indication, or to a standard recording unit for making a permanent record. The fabricating tool itself may be a modified lathe, pressure molder, punch press, or any of the basic production machines required for a given operation. Many new types of machines will appear as soon as a new philosophy of design is developed. These machines, and the products they make, will be unlike anything we have today. Products are always designed in terms of the production machine.

A factory is an aggregation of production, assembly, and handling machinery, controlled from a central position. The automatic factory will be made up of many production-machine units like the one described above, each making a single part, one connected to another by a conveyor system, and all linked through a central master control panel. Its automatic operation will start from the point where automatic transport units unload raw materials from truck or freight car and pass them through the first inspection.

Inspection is accomplished without human aid by means of information devices, available in great variety, for scanning, counting, testing, and so on. Each piece of material passes through the units in turn. Metal stock is tested for correct size and hardness, semifinished products for size, color, shape, material, and weight. Substandard pieces are automatically pushed

off onto another conveyor that takes them to either shipping or salvage. Materials that pass inspection are fed by conveyor to warehouse bins or directly to the production machines. The finished parts pass from the production machines, through another inspection, to subassembly and assembly machines.

The assembly machine, another kind of production tool, again employs the hand-arm type of unit, working over an assembly jig, controlled by a master record. The first part needed for an assembly is picked off the conveyor and placed in the jig. Having operated once, the hand-arm that supplied this part cannot work again until it is triggered. When the parts have been assembled in a jig, a riveting, welding, or induction heating device darts in to fasten them together and the finished product is ejected. For most products a moving line of assembly jigs would probably be used, with a radial system of conveyors feeding in completed parts and subassemblies. . . .

In such a factory the human working force is confined to management, which makes the policy decisions as to how many of what items to produce, and an engineering and technical staff, which carries out the decisions. If a product is to be changed, new specifications for a new product in the form of punch cards or blueprint records are substituted for the old in the master record-control racks. Teams of technicians go down on the production floor to rearrange, set up, and reconnect the interchangeable units of production. Then the continuous production run is started again.

An economy that makes full use of such production machinery will be so different from the present it will constitute a new industrial order. The advantages to management are, perhaps, obvious. Higher volume and cheaper goods are immediately discernible. The production rate will be higher, not being limited to human considerations anywhere in the chain. The production rate will also be constant and continuous, permitting a close figuring of costs. Both man-hour and machine-hour production rates will be incomparably higher, and consequently goods will be cheaper. They will also be better, because the machines will achieve much greater precision in manufacture, controlling tolerances of all kinds much more closely than now.

The great adaptability of the new machines will make for an

industry that is quick on its feet. Interchangeability of basic units will allow a manufacturer to accommodate himself to sudden changes in the market, turning from hearing aids, say, to intercommunication sets practically overnight. A maker of vacuum cleaners, noting a bottleneck in the delivery of phonograph motors by regular suppliers, could in a matter of days slip in a short run of phonograph motors. Such versatility of production would make the market more responsive to supply and demand, therefore more competitive, and therefore would keep levels down. Also it would keep new products coming faster. . . .

This is well illustrated in a potential new branch of the aircraft industry, the manufacture of helicopters. There is no doubt that a small but substantial demand exists and might grow larger if price could be brought under $5,000. But the only way to get price down to this level is to mass-produce, and mass production under the present system means an investment of millions in specialized machines, jigs, and fixtures. Since helicopter design is changing rapidly, the whole factory might be obsolete before the first unit was sold. Under these circumstances mass production is a very poor risk. If the aircraft industry were tooled up under the new system of flexible machine units, however, a small part of production could be turned over to meeting the present demand at lower cost, and expanded or changed over as rapidly as new designs grew. No matter how radical the changes were, they could be quickly applied to the product merely by making changes in the master record and resetting the machine units. . . .

The disadvantages of the new machines are greater initial complexity and greater initial investment—at least in their first development. The only major disadvantage, however, is one that is shared with everything useful ever invented. The new machine is new, and involves the scrapping of old ideas and most present factory equipment. But present equipment, being inflexible, is going to be scrapped in any case and replaced with machines equally inflexible. We propose to replace them with a new kind of machine.

Replacement of machines means replacement of men, and here the advantages may be more hotly challenged. The auto-

matic factory may well loose waves of temporary unemployment. But the long-range benefits are hardly to be contested. It is better to regiment machines than men. The whole trend of present automatic controls and devices applied to present production machines is to degrade the worker to an unskilled and tradeless nonentity. The development of completely automatic production lines would reverse this by demanding a highly skilled force of technicians and operators. The astonishingly rapid development of new skills and occupations under the pressures of war shows that men are up to it. By the use of training programs, a shorter work week, and other devices, the shocks of transition could be cushioned. Here for the first time we have a production system so potentially efficient that the two-or-three-day week is economically feasible. This system is designed to supply a mass market, and without the mass market it would be worse than useless. Its cheaper costs could be passed on in higher wages to the worker and greater value to the consumer. It must, therefore, balance out at a higher level of living than ever before.

Many of the ills of modern industrial society can be traced in large part to the regimentation of workers and other materials that do not take kindly to it; and the failure to regiment machines that are ideally suited to it. Our present industrial system tends to regiment the worker and destroy his skills and initiative, without a compensating measure of economic security. Regimentation of machines cannot hurt the machines, and can emancipate the worker forever from degrading or monotonous toil.

WILLY LEY

Rockets, Missiles, and Space Satellites

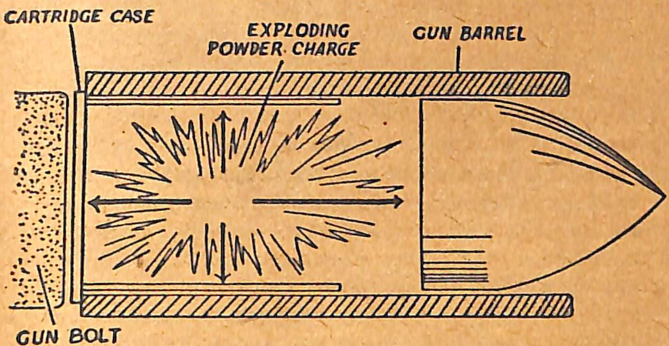
The following article was prepared before the electrifying announcement, in July, 1955, that American scientists would launch a man-made moonlet as part of their activities for the International Geophysical Year, the great international program for study of the earth and atmosphere scheduled for July, 1957, to December, 1958. (Later, it was announced American scientists hoped to launch ten artificial satellites, of which it was expected five or six would be successful; a Russian space-satellite project was also disclosed.) In any event, it is clear that rockets are here to stay and have an important future in transportation as well as defense and upper-air research. Mr. Ley's article was written especially for this book. Mr. Ley, who also drew the diagram of the three-stage rocket, has both experimented with and written about rockets for many years.

In the days of Napoleon Bonaparte, soldiers knew that nothing could happen to them a mile from the battlefield. At the time of the Spanish-American War, three miles was a safe distance. During the first World War, twelve miles behind the trenches was quite safe unless somebody flew an air raid. In World War II, fighter-bombers made the zone of acute danger 100 miles deep, and points hundreds of miles beyond that were only relatively safe because of large-scale air raids.

Since the second World War, it has been widely predicted that the future would bring intercontinental missiles with a range of 5,000 miles. One cannot say how far along in the process of development such missiles are. But they are certainly

under intense study.

An intercontinental missile might be achieved in either of two ways. It might be what aeronautical engineers term a cruising or flightpath missile, or it might be a trajectory missile. A flightpath missile is essentially an unmanned airplane. Soldiers sta-



WHY GUNS RECOIL

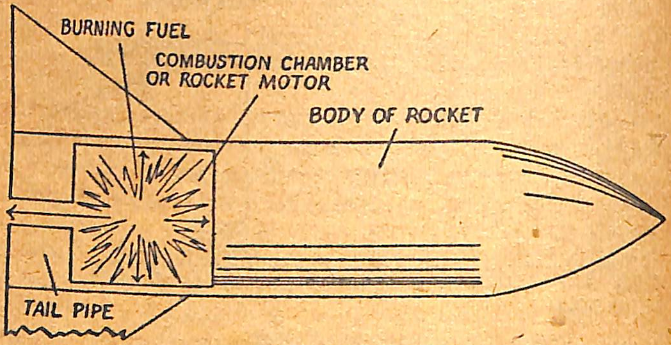
Gas from exploding powder charge pushes in all directions. Gas pushing up offsets gas pushing down. Gas pushing forward drives bullet out of gun band, then escapes. Gas pushing back drives cartridge case back against gun bolt, making gun move back or recoil.

tioned in England during the last year of World War II were well acquainted with flightpath missiles. The V-1 buzz bomb was one.

Like most airplanes, the flightpath missile takes off at a slant; it has wings to support it; and it is propelled by an "air-breathing engine," that is, an engine that depends on an outside source of oxygen to burn its fuel. In theory, flightpath missiles can employ any type of engine. In practice, they use the simplest, cheapest type of jet engine since the missile flies only one mission.

Flightpath missiles fly at relatively low altitudes (because of the need for air) and at relatively low speeds; they can be inter-

cepted, successfully, as the buzz bombs often were. Trajectory missiles fly much higher and faster. They operate in the nearly airless regions fifteen miles and more above the earth. To do this, they must carry a source of oxygen as well as fuel; and they have to utilize the one method of propulsion that will work in a vacuum. In short, like the German V-2 (which soldiers in



WHY ROCKETS MOVE

Gas from burning fuel presses in all directions. Gas pushing up offsets gas pushing down. Gas pushing back escapes through tail pipe. Gas pushing forward has no place to escape, drives rocket forward.

London in the last year of the war also knew well), trajectory missiles are and must be rockets.

The principle of the rocket goes back to thirteenth-century China; the rocket is older than the gun. Rockets are propelled by recoil, the force that makes a gun kick when it is fired. Recoil originates from the rapid conversion of gunpowder (or other fuel that burns with explosive speed) to hot gas inside an all but completely closed-in firing chamber. The expanding gas (see diagrams) presses in all directions. In rocket and gun alike, the thrust of gas up and down and to the sides is offset by an equal thrust of gas in the opposite direction. In the gun, the forward thrust of the gas sends the bullet on its way and the

rearward thrust drives the gun against the shooter's shoulder. In a rocket, the opening of the combustion chamber is to the rear. So rearward-expanding gas escapes, while the gas pushing forward presses against the *forward* wall of the chamber and "recoils" the rocket forward.

It is often thought that rockets are driven forward by the push of escaping gas against the air behind the rocket. This is not so. If it were, rockets would not work in a vacuum. In fact, they work better in a vacuum than in the air, since the escaping exhaust gases are not slowed down by air resistance and since the drag of the air on the rocket itself is eliminated.

In signal and Fourth-of-July rockets, the usual propulsive charge is a gunpowder-like mixture of sulfur, charcoal, and saltpeter. The sulfur and charcoal represent the "fuel," while the saltpeter furnishes the oxygen. In modern military bombardment rockets, the propelling charge is a "stick" of smokeless powder which also burns without the need of oxygen from the air.

All rockets that burn a "gunpowder" of some kind are known as solid-fuel rockets. Curiously, for some time the largest solid-fuel rocket was an airborne rocket designed to be fired against ground targets. Nicknamed Tiny Tim, it was 10 feet 3 inches long and weighed 1,284 pounds. A more recent solid-fuel rocket, Honest John, an Army missile meant to be used from the ground like heavy artillery, is even larger.

Large as some are, solid-fuel missiles are dwarfed by liquid-fuel rockets. As their name states, the latter carry a liquid fuel and a liquid oxidizer in separate tanks.

To keep their weight down, really large liquid-fuel rockets have thin skins. Consequently, they cannot be fired through an aiming tube (the tube would tear their skins off), but must be stood on their tails for a vertical take-off. Thus, large rockets should be described from top to bottom rather than nose to tail like a plane, although the terms nose and tail are retained.

The nose of a typical liquid-fuel rocket contains the payload —an explosive warhead if it is a military missile, an "instrumentation cone" for recording and radioing back observations on conditions in the stratosphere if it is a research rocket. Next

come the instruments that control the rocket itself. Below this section are the fuel tanks, which make up the largest part of the rocket. The last section of the rocket, between the tail fins, houses the "rocket motor" (the combustion chamber and tail pipes) and auxiliary equipment, such as fuel pumps.

Rockets have no internal ignition system. Most are ignited externally, by an electric spark (as in the case of the World War II bazooka), or by putting a flame in the exhaust nozzle (as is done with many liquid-fuel rockets). Some liquid-fuel rockets, however, employ a combination of chemicals, such as nitric acid and aniline, that burst into flame spontaneously on contact with each other. In any event, rockets burn until their fuel is gone or (in the case of liquid-fuel rockets) until the pumps stop delivering fuel to the combustion chamber.

Rockets that take off vertically continue to rise vertically until they have gathered speed. An internal mechanism then tilts them in the direction of the target. There are several methods of accomplishing this. The V-2 was tilted by means of graphite vanes in the exhaust blast. In the Viking rocket, the whole rocket motor is mounted in such a way that the motor itself can be tilted. Research rockets are generally tilted just enough to prevent the rocket from falling back on the launching site. Military rockets are tilted until the rocket is climbing at a slant of about 45 degrees, an angle at which it continues until the fuel flow is cut off. After that, the military rocket behaves like an artillery projectile: it continues to climb with diminishing speed, reaches the high point of its trajectory halfway to the target, and then approaches the ground.

When it comes to long-range military rockets, most of the difficulties can be summed up in the one word "guidance." There can be no guidance worth mentioning once the power is off. All of it has to be applied in the minute or so after take-off that the rocket motor burns.

To hit a target, the rocket must be traveling, at the instant the flow of fuel stops:

a) in precisely the right direction,

b) at precisely the calculated velocity,

c) with precisely the calculated angle of climb, which in turn depends on

d) the exact distance from the take-off point, and

e) the exact distance from the ground at the moment the fuel is cut off.

Even a small error in any of these calculations (not to mention unknown winds and so on as the rocket approaches the target) will lead to an impact miles away from the target point simply because of the great distances involved. If the deviation of actual impact point from the theoretical target point is expressed as a percentage of the range, one finds—not counting cases of obvious malfunction—that the V-2 was nearly as accurate as a field howitzer. But since it was fired over a range of 200 miles and climbed to a height of more than 60 miles along its trajectory, V-2s scattered over the whole area of metropolitan London. It is interesting that the Germans, foreseeing such scatter during practice firings, placed their observers right at the theoretical target point. Just as expected, the men were close enough to the impacts to observe them, but no rocket fell closer than 1,000 yards. It is clear that guidance will remain the main problem in trajectory missiles, and new trajectory-missile guidance devices the most closely guarded secret, for years to come.

While little has been said about actual progress in long-range military missiles, in the field of high-altitude shots every record established has been broken soon afterwards. In 1943, a V-2, fired on a near-vertical trajectory, reached an altitude of 100 miles. In December, 1946, a captured V-2, fired from the White Sands Proving Ground in New Mexico as No. 17 of the U.S. V-2 high-altitude research program, reached a height of 114 miles. This record was soon topped by another V-2, fired outside the high-altitude program, that climbed to 128 miles. In August, 1951, the U.S. Navy rocket Viking VII soared to 135 miles and in May, 1954, Viking XI established the current high-altitude record for single-stage rockets—158 miles.

The qualifying phrase "for single-stage rockets" has to be used because the over-all altitude record of 250 miles had meanwhile—on February 24, 1949—gone to Bumper, a two-stage rocket. The latter is simply an arrangement in which the payload of one rocket is another rocket; each rocket is then termed a stage, and they are numbered in the order in which they

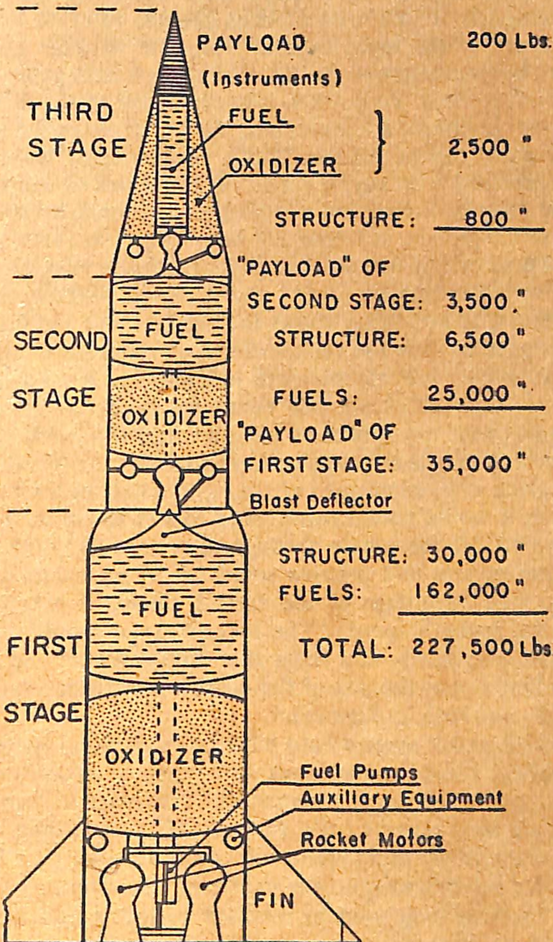
burn. In Bumper, the first stage was a V-2, and the second stage—the rocket which the V-2 carried and which was ignited after the V-2 burned out—was a WAC Corporal.

In order for a multiple-stage rocket to attain the greatest possible altitude, there must be no time interval between the burning of the stages, else velocity and with it altitude or range will be lost. In the case of Bumper, the first stage reached maximum velocity—roughly a mile a second—65 seconds after take-off and 20 miles above the take-off site. Then the second stage took over and lifted itself out of the burned-out first stage. Of course, the first stage kept rising too, for a time (to a maximum of about 90 miles), but it was then coasting without power and losing speed steadily, while the second stage forged ahead.

The example of Bumper is important when intercontinental missiles are considered, for the latter would have to be at least two-stage rockets, and they might have to have three stages. Naturally, little has been disclosed on the horizontal (as contrasted with vertical) range of large rockets, but theoretical calculations make it seem as though 500 to 600 miles would be the maximum horizontal range for single-stage rockets. Similarly, a two-stage missile might reach 1,200 to 1,500 miles. But beyond that, three stages would be necessary.

Multi-stage missiles involve a number of practical difficulties. If the third stage of a three-stage missile has a range of 5,000 miles, the second would strike the ground about 1,200 miles from the take-off site, and the first, 400 to 500 miles from it. Though the burned-out first and second stages are just hot metal, they ought to come down in enemy territory, the open ocean, or Arctic snowfields. If not, provision must be made for them to "land" rather than crash. It can be done, but not easily.

Long-range trajectory missiles fly at altitudes not far below empty space. At 80,000 feet, an altitude already reached by piloted rocket-propelled aircraft, 96 per cent of all the air in the earth's atmosphere is already below the pilot. At a height of 100 miles, far less than one per cent of the atmosphere is still above the rocket. At the altitude reached by Bumper, what is left of the atmosphere is less dense than the vacuum inside a television picture tube.



Cross section through a three-stage rocket capable of carrying 200 lbs. of instrumentation into a closed orbit around the earth. The weights given are calculated for currently available and well-tested fuels. The three-stage assembly would stand about 100 feet tall at take-off.

It would be of interest to learn what conditions prevail at those altitudes. It would be of even greater interest to make observations of the space beyond from the vantage point of those altitudes, far above the interfering dust and gases of the earth's atmosphere. To do this, it is necessary to put a missile into space not just for a few seconds, but for an extended period.

How could this be managed? If a rocket, after leaving the atmosphere below at, say, a height of 200 miles or better, had a lateral velocity of four and a half miles a second, it would not return to the ground. It would not be outside the earth's gravitational field by any means. But, at that altitude and speed, the missile would merely be forced into a closed path around the earth. Since, at 200 miles above the earth, there would be no air resistance to slow the rocket down, the missile would continue on its path around the earth indefinitely. An astronomer would say that the rocket had taken up an orbit around the earth, just as the moon is in an orbit around the earth.

A research missile might be got up to an altitude of 200 miles, and be given a lateral velocity of four and a half miles a second. However, it would take a three-stage rocket to do it. The first stage would lift the whole through the first 100,000 feet of dense atmosphere and provide some tilt in an easterly direction (to take advantage of the earth's eastward rotation and add to the rocket's speed). The second stage would continue the climb. The third—the stage that would travel the orbit—would climb out of the last of the earth's atmosphere at a shallow angle, and turn into the orbit.

The third rocket stage would have as its payload instruments which would record the amount and types of radiation above the atmosphere; of the frequency and character of cosmic-ray impacts on the rocket; of the amount of cosmic dust present; and of many other things that will occur to scientists long before such a satellite missile is constructed. Telemetering devices similar to those long used in weather balloons and in present high-altitude research rockets would radio collected data back.

Interestingly, an even simpler artificial satellite, one that carried no instruments at all, would be of great scientific value. For the size and shape of the orbit it took would reveal a great deal, both about future larger satellite vehicles and about the

earth and gravitational force. In its simplest form, an uninstrumented artificial satellite might consist merely of a plastic balloon inflated from a small pressure cartridge after the third stage has assumed an orbit, or else a bubble of plastic foam. Anything that could be seen from the ground and that will give a radar echo would do. And it could be quite small: the most sensitive existing instruments could photograph a tennis ball in an orbit 1,000 miles from the ground, a 10-foot bubble 250 miles up would occasionally be visible to the naked eye as a slowly moving star.

Let us assume that a plastic-bubble uninstrumented satellite might weigh between six and eight pounds. Quite simple calculations show that the over-all take-off weight of the three-stage rocket needed to take it into its orbit would be seven and a half tons. Presumably no such three-stage rocket exists at the moment. But this is the take-off weight of Viking XI, and less than the take-off weight of the V-2. So there is no doubt that nothing is required for building it but the authority and funds to go ahead and build it.

Among the contributors to this volume are some of the world's greatest scientists and scientific journalists:

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